STUDIES OF THE PHYSICAL PROPERTIES AND REDUCTION-SWELLING BEHAVIOR OF FIRED HAEMATITE IRON ORE PELLETS

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By

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Certificate

This is to certify that the thesis entitled,**"STUDIES OF THE PHYSICAL PROPERTIES AND REDUCTION-SWELLING BEHAVIOR OF FIRED HAEMATITE IRON ORE PELLETS"** submitted by **Punit Kumar Eshwar (213MM1466)** in partial fulfilment of the requirements for the award of **Master of Technology Degree** in **Metallurgical and Materials Engineering** at National Institute of Technology, Rourkela is an authentic work carried out by them under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

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Place: Rourkela

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ABSTRACT

Keeping in mind, during the course of mining, a large amount of iron and coal fines are generated, a technique need to be developed to make use of almost useless fines. In my project work, we are making studies of reduction-swelling behaviour of nuggets made out from hematite ore under the influence of varying parameters. We studied the physical characteristics of fired iron ore pellets. As we increase the dose of binder, i.e., bentonite, the crushing strength & drop no. increases.

Objectives of this project work is to investigate the effects of (a) reduction temp. & time (b) content of bentonite on swelling-reduction properties of fired hematite nuggets. The extent of reduction of fired pellets observed to be increased as we raise the temperature from 850^{θ}c-950^{θ}c.The extent of reduction of fired nuggets are observed to increasing with increase in length of time provided to the pellets for reduction. At 850^{θ}c, maximum percentage swelling is observed. This is due to the growth of pellet matrix as can be seen from SEM pics. Lowest degree of reduction is observed at 800c and gives highest value at 950c.Pellets reduced at higher temperature as 900 &950, gives slight decreased value than pellet reduced at 850c because of sintering of pellet matrix as clearly seen in the SEM pics.

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INTRODUCTION

1.1 INTRODUCTION

Use of blast furnace is still most dominant process of producing primary iron. Nonetheless bottleneck associated with blast furnace caused the development of different alternatives processes like the mini blast furnace SR method and direct reduction methods. A number of processes are being worked on. In spite of direct reduction technique has come to appreciable level of commercially suitable, are thought to be the utmost advanced option of iron making. Direct reduced iron/ sponge iron-a solid permeable produce of direct reduction method, which can be produce either in pellet or lump form. DRI is a very competitive option of steel as a scrap for production of steel via EAF,BOF etc. ,as a result it brings about a rapid development in sponge iron market.

In perspective of all time high demand of sponge iron for producing diverse variety of steels, great focus is already being provided to encourage the enhancement of direct reduced methods.in the process of direct reduction, it provides decent adaptability for utilizing diverse kind of reductant such as low quality non coking coal, char coal, natural gas and so on. In the view of quick consumption of higher quality coking coals, stocks confines the utilization of coke in basic method of steel making course in India. Fortunately provided with superior quality of iron ore alongside abundant stores of non-coking coal, that can be keep going for an additional two hundred years or something like that India, unusual coal dependent sponge iron industry. Aggregate gross stores of coking and non-coking coal in India are 32 and 221 billion tons individually. By this perspective, the rotary kiln (coal based) DRI methods had grown exceptionally well and enthusiastically in India rather than natural gas based shaft furnace or retort furnace

Now a days, great focus is being given to direct reduction forms on the grounds that utilization of direct reduced nuggets or sponge iron for charging for the blast furnace,

induction furnaces and basic oxygen furnaces, even though some related disadvantages, offer higher degree by enhancing the productivity and economy by utilizing coke.

India has a vast store of iron ore. Especially hematite iron ore have substantial percentage.in vision 2020 survey the hematite reserves is discovered to be lessened yet in the meantime it is being indicated in the survey that steel will be created at 300 MT every annum except the benefit will be hampered due the absence of superior grade ore so the inferior grade ore will be utilized for steel making as to take care of the demand. The lower grade iron mineral is extremely troublesome in transportation and taking care of on the grounds that it have an extremely fine size. So this kind of iron metal is changed as a pellet which is can be utilize. As per Indian mines authority, iron mineral save in India as assessed on April 1, 2005, is around 14.63bt of hematite and 10.62 bt of magnetite. Out of the aggregate hematite hold in India, just 11% is of high grade, 50% of intermediate grade, 25% is of inferior grade, while the remaining 14% is un categorized. Presently, accessibility of high review iron mineral implied that beneficiation procedures in India did not oblige fine crushing of iron metal consequently, palletisation of iron mineral fines has not been extremely prevalent in India, as sintering methodology alone was ample to use the -10mm iron metal monetarily if India attains to 300mtpa of steel by next 25 years, as being proposed in vision-2020, its high- grade hematite store will be depleted by 2030- requiring beneficiation of poor quality iron metals.

With complicated beneficiation of lower grade iron metals after fine crushing, palletisation will get to be more critical in Indian steel scenario. World's trend in palletisation is basically with magnetic concentrates. Investigation of the palletisation behaviour of hematite metals will be obliged to advance the methodology parameters of palletisation. In the meantime, with the accessibility of more superior fines, notwithstanding sintering will need to be upgraded requiring further R&D enhancement. The significance of sponge iron is expanding yet the iron metal needed for fabrication of DRI must have particular characteristics like strength

wear resistance and so forth. The accessibility of such iron mineral is diminishing continuously. Thus, endeavour has been made to fabricate metallized pellet with a poor quality iron metal or iron mineral fines. These chunks are to be reduced at a higher temperature for further use in electric steel making procedure. Also this can likewise be utilized as a part of BOF process as coolant.

1.2 IRON ORE RESERVES

Currently, India is fifth as far as iron mineral stores. In its 25 billion tons of stores, out of Which 15 billion tons are accounted for to be hematite and rest magnetite having 55% iron according to Indian mines department. India yields around 155 million tons of iron ore (accounting lumps and fines both) out of which around 52 million tons were utilized by the domestic steel industries.

1.2.1 Iron Ore Reserves

India's position is very wealthy in the matter of iron ore stores worldwide. Iron mineral which is otherwise called hematite found in rich quantity in our country. Iron mineral store represents very nearly two third of the whole iron metal saves in India. India have the dominant position in the count of highest iron ore reserve nations.

In the aggregate iron metal holds in the nation,Sundargarh and Kendujhar in Orissa, singhbhum in Jharkhand,Chikkamagluru in Karnataka, Shimoga,Bellary and Goa represents significant part. Further in Orissa and Bihar, gigantic stores of iron mineral shows up as colossal masses that can be easily seen higher than adjoining plain. Some iron ore mines are

situated in a close vicinity to the coal field. Iron mineral by and large happens at top of the slopes and along these lines ethereal roadways are utilized by the iron metal organizations to take down the iron ore and for delivering it to the railway wagons. In Jharkhand, singhbhum district and the neighbouring district of Sundarand, mayurbhanj and Keonjhar have the highest grade iron ore stores.

In India main mining areas are Badampur and sulaipat in Mayurbhanj District of Orissa. And Noamundi and gua in Singhbhum district of Jharkhand. From these mines iron ore is supplied to the iron and steel commercial enterprises. The Rajhara and Dhali Hills situated in south of Bhilai issues its metal to Bhilai steel plant. Kemmangundi in the Bababudan slopes of Chikmagalur region in Karnataka is the wealthiest wellspring of high quality iron mineral. Wealthiest wellsprings of high quality iron metal are found in Madhya Pradesh, Goa,Bastar area, Maharashtra, Chandpur District and region of Orissa,Andhra Pradesh and Bihar. The aggregate obtainable stores of iron mineral in India, around 9,652 million tons of hematite and 3,404 million tons of magnetite.MP, Karnataka, Jharkhand, Goa, Odisha, Maharashtra, AP, Kerala, Rajasthan and TN are the essential Indian iron producing states.

States	Main Ore	Fe Range (%age)	Alumina (%age)	Phos Max (%age)
A-Orissa, Jharkhand	Haematite	62-64	2-4	0.04-0.1
B-Chattisgarh, MP, Maharashtra	Haematite	64-66	1.0-4.0	0.04-0.15
C-Karnataka	Haematite	62-64	2.0-4.0	0.04-0.09
D-Goa	Haematite	60-63	2.0-4.0	0.04-0.07
E-Karnataka	Magnetite	35-45	1.0	-

States	Major Mines / Deposits
A-Orissa, Jharkhand	Chiria, Noamundi, Joda, Kiriburu, Meghataburu, Thakurani, Bolani, Gua, Malangtoli, Gandhamardan, Daitari
B-Chattisgarh, MP, Maharashtra	Bailadila, Dalli,Rajhara, Rowghat, Mahamaya, Aridongri, Surajgarh
C-Karnataka	Donimalai, Ramandurg, Kumaraswamy, NEB Range, Ettinahatti, Tumti, Belagal
D-Goa	N Goa, S Goa, Redi
E-Karnataka	Kudremukh, Bebebudan, Kudachadri

1.3 TYPES OF IRON ORES

Hematite (Fe_2O_3)

Hematite is generally found greatly dispersed and is the best of iron ores in matter of iron content in it. In its purest form it contains approximately 70% iron. A large fraction of the mined hematite is high quality containing 65-70% iron and just little amounts of contamination, essentially silica and alumina. Sulphur and phosphorus substance if any are ordinarily low. Apart from this, a huge stores of inferior quality Fe_2O_3 containing approx. 20-40 % iron along with higher silica concentration. Great volume of the silica is eliminated by mineral handling; the produce contains 61-69 % of iron.

Magnetite (Fe_3O_4)

Stores of higher grade magnetite found in various places worldwide. Purest magnetite contains 72.6% iron, whereas the higher grade mineral typically having more than 60% iron with a few contaminants, for example, phosphorus, silica and apatite, as a typical polluting element. Inferior magnetite stores are likewise can also useful in different work, and an item is gotten after mineral enrichment which have iron quantity is as much as 60%.

Limonite, Goethite

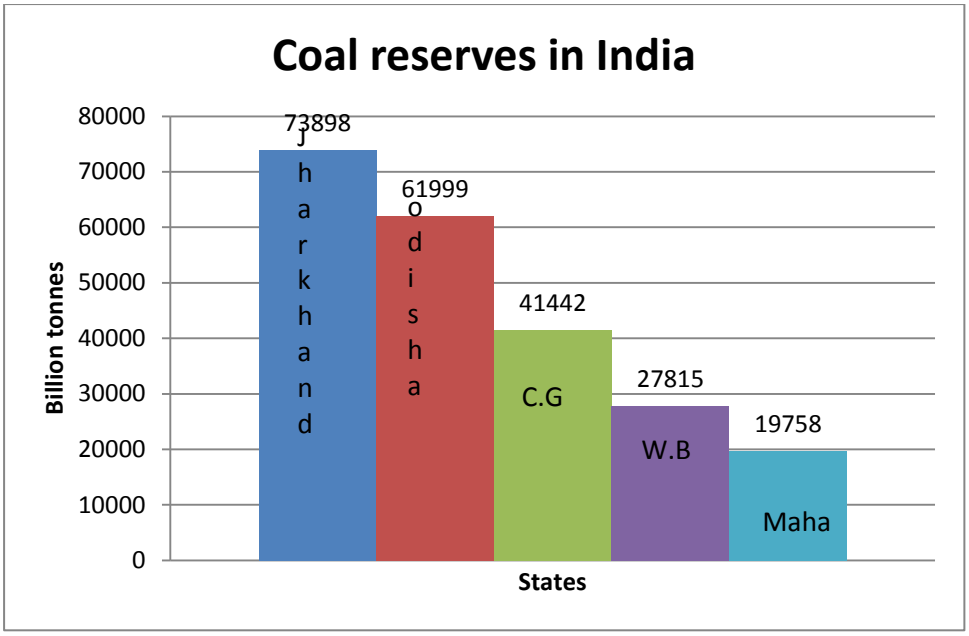
This kind of ore is in the form of hydride having iron content as 62-64%.They can also found as primary minerals and generally found close to the surface as a consequence of weathering of the uncovered ore.

Siderite ($FeCo_3$)

This kind of iron ore constitutes just a little extent of the aggregate world iron metal stores. In its purest form, having 48.8% iron, yet it is effectively disintegrated thermally (calcined) to hematite, with70% iron content, siderite, still an industrially vital source of mineral in a few nations.

1.4 Origin of Coal & Coal Reserves in India

Coal comprises of natural matter from ancient times that have been modified synthetically amid intense pressure and for a quite length of time, truly like the formation of oil from various perspectives. The gathering of residue, waste and comparable natural fixings began in marshes and swamps a great many years prior. Tectonic moves and developments in the Earth covering covered these regions, now and again down to great depth. The intense pressure surrounding along with the warmth from the Earth inside changed the natural matter by modifying its compound nature. First and foremost it was changed into peat and the peat subsequently refined into coal of distinctive varieties. The nature of a coal store is characterized by the weight, temperature together with the time. A finer quality coal as expected has been exposed to the intense pressure, higher temperature and more residual times than coal of poor quality. Nearly 9500 years had taken to form peat kind of coal on the other hand it takes millions of year to form the anthracite.



1.4.1 Coking Coal

Coking coal, the derivative of coal which is formed when coal is heated to 350-550 without air, the process is also known as carbonisation, underwent changes into liquid state, increase in volume and then crystallizes to form cake. On extinguishing the cake brings about a solid and permeable mass called coke. Coking coal can be partitioned into 3 sub-classes to be specific

- Primary coke
- Medium coking coal
- Semi soft coking coal

1.4.2 Non-Coking Coal (NCC)

Unlike the coking coal, these coals have meagre coking abilities that are. It don't soften and structure cake like coking coal amid carbonization in the coke furnace. These coals with moderately lesser ash and maximum fixed amount of carbon are utilized as a part of metallurgical uses for example COREX innovation based iron (pig iron)plants, DRI units based on and so forth., while coals with maximum ash, generally utilized as a part of Power Plants.

1.5 Required properties of Coking coal for Blast Furnace:

1.5.1 Chemical properties:

The coke which is to be use in blast furnace must have to fulfil some parameters such as ash content should be less than 9.5,volatile materials must be in the range of 20-25% and sulphur content should be kept as possible as little like 0.6%,Alkali (K_2O+Na_2O) should be 0.25%,phosphorous 1-1.2%.

1.5.2 Physical properties:

There some set physical properties like strength, stability of the coke and strength of the coke after reaction with co_2 which are vital. Stability denotes the resistance to breakage. CSR determines the capability of the coke to disintegrate into finer size under an elevated temperature CO/CO2 atmosphere.

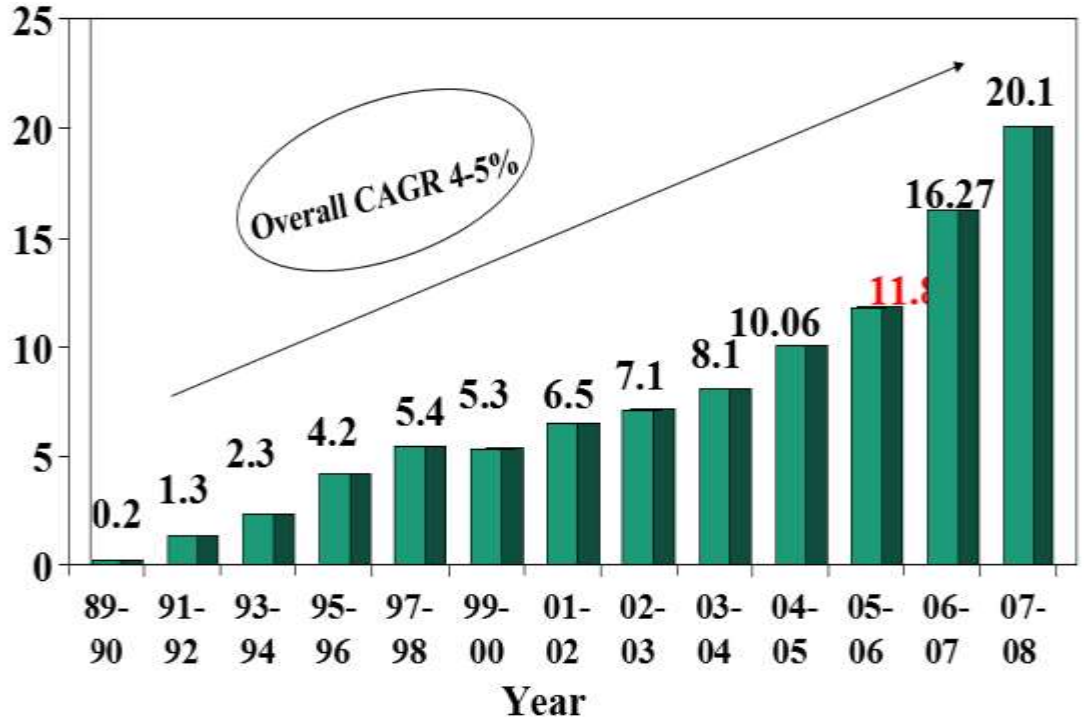
1.6 Details of DRI Production in INDIA and in the world

Yearly generation of direct reduced iron worldwide incorporating India is provided in Table. As per current investigation, it has been noticed that beginning with a small manufacturing o f0.79 million tons in 1970, the world reduced iron generation reached to 55.85 million tons in 2005, as provided in table-1.it is clearly seen that the world direct reduced iron creation, expanded almost 225% from the year 1990 to 2005.In the year 2002, India turned into the biggest manufacturer of DRI worldwide with a generation of 5.48 million tones and till now it has held its first position worldwide rating of sponge manufacturing. Out of 16.27 MT of wipe iron delivered in 2006-07 the commitment of coal based wipe iron units is nearly 11.01 MT and that of the gas based units is 5.26 MT. This huge distinction in commitment of G.B.S.I.U.

what's more, C.B.S.I.U. is because of shortage of required gas and plentiful accessibility of non-coking coal in country. This substantial development of DRI producing units is driven by expanding interest of steel in domestic market and additionally worldwide. Presently India is the 6th biggest steel maker on the planet with a manufacturing capacity of 42 MT per annum.

TABLE 4.1 Sponge Iron Production Scenarios in India and World

Year	World Scenario		Indian Scenario	
	Production(MT)	Growth (%)	Production(MT)	Growth (%)
1990-91	17.68	-	NA	-
1991-92	19.32	9.27	1.31	NA
1992-93	20.51	6.15	1.44	9.92
1993-94	23.65	15.30	2.40	66.66
1994-95	27.37	15.70	3.39	41.25
1995-96	30.67	12.00	4.40	29.79
1996-97	33.30	8.40	5.00	13.63
1997-98	36.19	8.88	5.30	6.00
1998-99	36.96	2.50	5.22	-1.50
1999-00	38.60	4.10	5.34	22.98
2000-01	43.78	11.90	5.48	26.21
2001-02	40.32	-6.99	5.43	-9.12
2002-03	45.08	12.00	6.9	27.07
2003-04	49.45	9.69	8.08	17.10
2004-05	54.60	12.00	10.30	27.45
2005-06	55.85	9.69	11.47	11.35
2006-07	59.8	10.41	16.27	-
2007-08	68.5	-	20	-



1.7 DISTINCT FEATURES OF SPONGE INDUSTRY IN INDIA:

In our country, not at all like in several different nations, natural gas and coal both had been utilized.

• In Indian sponge iron industry, firstly coal is prevailing followed by natural gas - currently coal's stake is 70%, on the other hand gas's stake is 75-80%.

• Arrangement of several revolving kiln furnaces based on coal is wasteful, is another unique characteristic.

• These coal based units regularly have furnaces equipped for specifically utilizing DRI fines down to 3mm.

• India, the sole nation among the countries of the world utilizing induction furnaces on such an expansive scale to manufacture steel in the auxiliary area. Reason?

• several industries using small mills have closed down their electric arc furnaces and introduced induction furnaces of 1-20 t capacity.

• Melting processes are upgraded in such a manner to manufacture and deliver small phosphorus and low sulphur high quality steel.

• Nearly 30% sponge iron had been constantly feed in induction furnaces even without altering the general working manner, in a few furnaces, up to 84% sponge iron had been utilized. Praise to advancement in Indian technologies.

1.8 SCOPE OF SPONGE IRON INDUSTRY IN INDIA

Price of and accessibility of gas would be crucial for sponge iron industry using gas. Price of the gas liable to increment. Financial aspects??

• Accessibility of suitable coal would be the driving factor for the eventual fate of coal- based plants. Dressing of non-coking coal is one of the important factor to furnish aggregate sponge iron request.

• Non-coking coal import from foreign countries like Australia and so forth will fulfil the demand.

• Impact of coal-based units on the environment has not generally gotten consideration. Efforts are required across the country to use this facility for a longer time.

• Rotary ovens utilizing coal and natural gas heaters utilizing characteristic gas will be even in automated plants.

• Apart from the gas produced from coal and gas, gases produced from different sources (CBM and so forth.) will be also crucial.

1.9 Thermodynamics and Kinetics of Iron Ore Reduction

Chemical Reactions:

In direct reduction process, iron oxide is reduced to metallic iron by both gaseous reducing agents like CO and H_2 and solid reducing agents for example solid carbon.

Steps of Reduction of hematite with Solid reductant:

$Fe_2O_3 + C \rightarrow Fe3O_4 + CO$, $\Delta H1 = 28.58$ Kcal. --- (1)

$Fe_3O_4 + C \rightarrow Fe + CO$, $\Delta H2 = 49.68$ Kcal. --- (2)

$Fe + C \rightarrow Fe + CO$, $\Delta H3 = 37.39$ Kcal --- (3)

The process of reduction of hematite ore firstly started with carbon like we can see in the above reaction and the solid carbon reacted with iron oxide to form CO gas which again take part in the subsequent reduction process.

Steps of Reduction of hematite ore with CO:

$Fe_2O_3 + CO \rightarrow Fe_3O_4 + CO_2$, $\Delta H4 = -12.87$ Kcal --- (4)

$Fe_3O_4 + CO \rightarrow FeO + CO_2$, $\Delta H5 = 8.56$ Kcal. ----- (5)

$FeO + CO \rightarrow Fe + CO_2$, $\Delta H6 = -6.88$ Kcal ----- (6)

$C + CO_2 \rightarrow 2CO$, $\Delta H7 = 41.28$ K cal ---- (7)

Carbon monoxide obtained from, carbon-gasification reaction, reaction between solid carbon and iron oxide and, by oxidation of carbon, further take part and reduces the remaining hematite ore to their subsequent oxidation level and carbon dioxide evolved as the result of reaction repeatedly mixed with carbon to give carbon monoxide and again this carbon monoxide do the same course of reduction of iron oxides to their lower states.

Steps of Reduction of Iron Oxide by H_2:

$Fe_2O_3 + H_2 \rightarrow Fe_3O_4 + H_2O$, $\Delta H8 = -3.07$ Kcal ----- (8)

$Fe_3O_4 + H2 \rightarrow FeO + H_2O$, $\Delta H9 = 18.32$ Kcal ----- (9)

$FeO + H_2 \rightarrow Fe + H_2O$, $\Delta H10 = 59.28$ Kcal --- (10)

$C + H_2O \rightarrow CO + H_2$, $\Delta H11 = 21.717$ Kcal --- (11)

Hydrogen gas reacts with hematite to reduce them to subsequent oxidation level and yields water molecules like mentioned in the above reaction (8), (9), (10).Water molecules obtained from the above reaction get reacted with carbon to give hydrogen and CO and the hydrogen and carbon monoxide which keep taking part in reduction of hematite ores.

Oxidation of Solid Carbon:

$C + O_2 \rightarrow CO$, $\Delta H13 = -94.08$ Kcal ------ (12)

$C + O_2 \rightarrow CO_2$, $\Delta H14 = 25.35$ Kcal ------- (13)

Carbon dioxide and carbon monoxide is formed when carbon of feed materials are get oxidized due presence of air in the kiln. .Thus CO that we get, reacts to reduce the hematite ore, and the CO_2 react with carbon to form CO and the same process will continue.

1.10 VARIOUS METHODSPRODUCINGSPONGE IRON

a) Coal based processes:

1) Rotary kiln processes (SL/RN, Krupp-CODIR)

2) Retort processes (KinglorMetor)

3) Rotary hearth processes (Inmetco, FASTMET)

b) Gas based processes:

1) Shaft processes

2) Fluidized processes

1.10.1 Coal Based Technologies

In the manufacturing of direct reduced iron, non-coking coal and iron ore is the chief starting material. The charge material comprising of requisite amounts of iron mineral, non-coking coal &calcium carbonate is charged consistently to the rotating drum of the kiln at the charging end. Because of its position that is some angle with the horizontal and the rotation of the drum, the feed material travels from charge end delivery end .The atmosphere needed by the process is regulated and keep consistent pre-requisite amount of hot air infused into the furnace by the help of air vessels throughout the length of the oven. The process requires delivery end of the furnace to be maintained at 950°C to 1050°C.To maintain this high temperature requirement, additional combustible material such as petroleum oil, combustible gases and fine crushed coal alongside air are forced through the focal burner at the delivery end of the furnace. The stream of the gasses is made opposite to the material stream. The arrangement is normally worked with little positive than atmospheric pressure to avoid the entry of the ambient air. While the travel of the charge through the rotating drum, mixture of iron mineral lumps and coal rejected the moisture and taken to the requisite temperature needed for the reduction in the primary stages and subsequently iron mineral is reduced by reducing gases generated from the coal under regulated combustion atmosphere. When the feed material approached the delivery end of the kiln, the iron ore pellet will reduced almost.

The final metallic product and unused charge material, coal typically called char is taken out of the cooler. To avoid any danger, the char is cooled up to 100KC with the help of water jets

spraying before releasing to the outside atmosphere. The product from the cooler section is taken to another material division system where there is a magnetic kind of arrangement which separated sponge iron (magnetic) from char which is usually nonmagnetic in nature. The flue gases coming out from the kiln forced through dust separating chamber, where heavier dust particles sink down located beneath the ABC (After Burner Chamber), where unused coal particles and gaseous products are burnt. The gases consisting finer dust particles go straightforwardly through waste gasses cleaning framework or through waste gas heat recuperation kettle and cleaning framework as the case may be diminishment of the iron metal will just about be finished.

1.10.2 Gas Based Technologies

The gas-based shaft furnace processes, which have become by far the most popular for the production of sponge iron, employ a vertical shaft furnace in which, as in the case of a blast furnace, lump ore and pellet are charged at the top using a charging system similar to a blast furnace. Reformed natural after pre-heating is introduced in the lower portion of the shaft. As hot reducing gas flows upwards, reduction takes place continuously. hence, these processes are often referred to as continuous counter current moving bed processes. In this category, the Midrex process is dominant, followed by HYL III and HYL IV.

1.12 AIM AND OBJECTIVES OF THE PROJECT:

- Investigation of physical characteristics of selected iron ores.
- Investigation on the effect of binder addition on the crushing strength, porosity and reduction behaviour of fired hematite ore pellets.

- Investigation on the effect of reduction temperature and time on the degree of reduction of fired hematite iron ore pellets.
- Investigation of effect of reduction temperature and time on the extent of swelling of iron ore pellets.
- Investigation of Correlation between Degree of reduction and Percentage swelling of iron ore pellets.
- XRD analysis of reduced iron ore pellets

CHAPTER-2

LITERATURE SURVEY

Investigation done by **M. Kumar *et.al***[1]tried to, kinetics involved in reduction underwent isothermally in hematite fired pellets, collected from 4 separate mines in Orissa, are done at the temperature limit of 850–1000◦C to give data to the sponge iron producing plants of country. Degree of reduction in every of the fired iron mineral nuggets went up especially with an increase of temperature till 950◦C, and from there on it diminished at 1000◦C. The rates were exceptional in the initial half an hour. Every single iron mineral showed practically finish diminishment in their pellets at temperatures of 900 and 950◦C in less than 2 hours length of heating time, and the ultimate item structure comprised of sensible breaks. The motor model comparison 1 − (1 − 1/3)=kt were observed best fitted to the investigation information, and the estimations of evident actuation energy were assessed. Degree of reduction of D. R. Mohanty and M. G. pattnaik iron mineral pellets were portrayed by higher initiation energies (184 and 150 kJ mol−1), showing carbon gasification behaviour to be the rate-controlling step. The outcomes made lower estimations of enactment vitality (83 and 84 kJ mol−1) for the decrease of G. M. OMC Ltd. furthermore, Sakaruddin iron metal pellets, proposing their general rates to be controlled by other than direct reduction.

Mohamed O.A et.al [2], the key parameters influencing the palletisation methodology of high, barite iron mineral concentrate were observed over utilizing the Egyptian typical and enacted bentonite for binding. The metallurgical behaviour of green, heated and terminated pellets were considered utilizing chemical and XRD. The normal strength of let go pellets containing 1.5% ordinary bentonite and heated at 13000C for 25 min surpassed 200 kg/pellet. Utilization of synthetic bentonite delivered an inferior strength in the pellet.

For this investigation work, M Kumar et al[3]physical and chemical properties and reduction characteristics of hematite minerals, obtained from 10 separate mines, were observed over in order to provide data give data to steel/iron companies (wipe iron plants specifically). Almost

all of the iron metals were found having high iron content and low alumina, silica particles. Furthermore every iron minerals does not have the pernicious components (Sulphur, lead, As, alkalis, and so forth.). The outcomes demonstrated lower estimations of smash and scraped area lists, and greater estimations of tumbler record in every iron metal bumps aside from Sakaruddin (past) and KhanduBandhu OMC Ltd. For every let go iron metal nuggets, level of reduction in coal were found extraordinary of the initial half an hour after that reduction got to be little. Moderate heating prompted higher level of decrease in heated pellets than quick warming. Every iron minerals displayed > 90% diminishment of their let go pellets in 120 minutes time interim at 9000C temperature. Iron mineral chunks indicated decreased level of reduction in comparison of heated pellets.

S.P.E. Forsmo et.al [4] had examined the methodology of sintering system in magnetite iron metal pellets. From their investigations they reasoned that Oxidation systems and warm volume changes in magnetite iron metal pellets as an element of crude material re-fineness, pellet porosity. At the point when a pellet begins to oxidize, a skin of hematite is shaped around the pellet while the centre remains is magnetite. Dilatation bends were recorded under non-oxidizing and oxidizing conditions to independently depict warm volume variation in these two stages. Dilatation estimations demonstrated withdrawal amid oxidation somewhere around 3300 and 900 °C by 0.53%.The degree of constriction was not impacted by crude material fineness or the first porosity in the pellets. At the same time with the constriction in the hematite shell, straight extension in the magnetite centre occurred. Sintering began before in the magnetite centre (950°C) contrasted with the hematite skin (1100 °C). The distinction in degree of sintering expanded with expanding fineness in the magnetite concentrate. A better crushing in the raw substance would, accordingly, advance the development of duplex geometry.

In this work Liu Gui-su et.al [5] have researched utilizing a few progressed experimental procedures on the principal kinetics for reduction of iron mineral using coal-fines. At first the thermal characteristics of coal-fines were inspected and clear particular warmth of coal-metal mixtures against temperature was gotten at rate of 10° C/min. We got several heat releasing and heat absorbing peaks were investigated which were identified with the disintegration responses and decrease. The vent gasses coming out the mixture were examined utilizing a mass spectrometer. Besides, the X-beam diffraction (XRD) and the iron stage investigative procedures were connected to recognize the iron stage changes with the temperature. It had been observed that coal decomposition and reduction of iron mineral happen all the while amid the warming of the mixture. H2 and CO gasses delivered from coal decomposition and burn gasification were key regulators in reduction of iron minerals at, these temperatures. Iron mineral experience gradual decrease over the entire procedure.

O. Sivrikaya et.al [6] has experimented utilizing advanced binder comprising of a natural binder and a chemical salt of borate was tried as a different option for bentonite in magnetite mineral pellet making. Calcinedcolemanite, corn starch, Carboxyl methyl cellulose (CMC) were utilized as natural binder separately. Diverse matches at a few expansion levels were added to pellet nourish independently. Natural binder utilization is discovered to be sufficient regarding quality wet pellet; on the other hand, they miss to render the obliged crushing strength to preheated and terminated pellets. Hence, natural binders and calcinedcolemanite utilized together so that wet pellets, preheated and let go pellets would be of the obliged quality, The outcomes demonstrated that the utilization of a natural along with calcinedcolemanite without a doubt yielded pellets with equivalent or better wet and acclimate pellet qualities contrasted with the pellets delivered with use of bentonite binder only.

In the experimental work done by B.K.Pandey et.al [7] to observe the impact of reducers(Non-coking coal, coke, , Charcoal, Char, , and so on.), on the reduction properties of two fold layered pellets comprising of a centre of iron metal and blend of reducing mixture inside a skin of iron mineral. The decrease tests were directed in isothermal atmosphere in the temperature limit of 1100–1200°C. The variables (parameters) observed were the temperature, carbon/iron oxide concentration of the centre, and time of reduction. The tests were factually composed such that, impact of every variable and inter-related impact of every variable can be quantitatively evaluated and thought about. The outcomes show maximum level of lessening with non-coking coal took after by charcoal, scorch and coke-fines. Amid these all parameters, time of reduction has the substantial impact when non-coking coals and charcoal are utilized as decreasing specialists, though on account of coke and singe, temperature of reduction has the substantial impact. C: Fe2O3 proportion of centre has the minimum impact in each of the four sorts of carbonaceous centre two fold layered pellets.

M.Kumar et.al [8] observed in their experimental work that observations of synthetic and physical properties (sulphur concentration, proximate investigation, reactivity, iron mineral diminishment potential, reactivity and ash combination temperatures) of coals, collected from sixteen separate mines, were embraced for their legal choice in Indian wipe iron plants. They found that these coals have low sulphur (limit: 0.40 – 0.65 %) and medium to maximum ash (range: 21 – 52 %) concentration. The conclusion showed, no caking properties in every coals sample aside from Basundhara. Almost all of the contemplated coal powder showed to have higher combination temperatures (ST: 1348 – 15490C; HT: 1500 – 15530C; and FT: 1510 – 15970C). Likewise an increment in fixed carbon concentration in the coal burn, when all is said in done, prompted abatement in its reactivity towards CO2, and maximum of the scorches showed essentially higher reactivity's less than 4.0 cc of CO/g-sec. Further studies on

reduction in coal scorches at 9000C showed an increment in the level of diminishment of terminated hematite iron metal pellets with expansion of singe reactivity and decrease time. The researcher prescribe the use of all the contemplated coals all things considered and few of them (Lakhanpur, Orient OD– 4, Samleshwari and Dhara coals) in the wake of mixing.

S. Komar Kavatra et.al [9] had made pellets from both iron mineral namely hematite, magnetite by the help of bentonite commonly used binder. Natural hematite and magnetite are moulded in the form of pellet and checked for crushing strength and drop number. Pellets made from hematite passed the safety check of 5 drops and crushing strength of 22N/pellet without any help of any binder, while pellets made from magnetite passed the industrial eligibility number with the addition of bentonite of 6.6 kg/t (0.66%).It is realized that better particles build pellet stronger, so extra magnetite crushed to the same size as the as-got hematite. The crushed magnetite is moulded in pellets and checked for drop no. and crushing quality. Wet drop and dry smash values expanded in the wake of fine crushing of magnetite mineral. Then again, they were essentially not as much as hematite pellets at comparable bentonite concentration. Subsequently, Particle distribution impacts were not the one of the main cause for higher qualities in the hematite mineral.

CHAPTER-3
EXPERIMENTAL

3. EXPERIMENTAL

3.1 Selection of Material

Iron ore is collected from G.M.OMC Ltd. and non-coking coal is taken from Basundhara mine of Odisha .Binder, bentonite is purchased by market.

3.2 Chemical Composition analysis of iron ore

Analysis of chemical composition of given sample was characterised by X-ray fluorescence method at Rourkela Steel Plant.

3.3 Proximate Analysis of Non-Coking Coal

3.3.1 Determination of moisture content

Moisture is determined by drying 1gm of sample at 105^0C for 1 hour. Weight loss is expressed in % of initial wt. of sample.

%M= (Weight loss/Wt. Of sample) ×100

3.3.2 Determination of volatile material

Volatile matter is the weight loss obtained on heating 1gm of sample of coal at 950^0C for 7 minutes in the absence of air.

Wt. loss due to V.M = Total wt. loss-moisture

3.3.3 Determination of ash

Ash is weight of reduce obtained after complete combustion of 1gm coal at 700-750^{0}C.Ash in % is

%A= (Weight of residue/Wt. of sample) ×100

3.3.4 Determination of fixed carbon

It can be determined as below:

% Fixed Carbon = 100 - % (moisture + volatile matter + ash)

3.4 PREPARATION OF IRON ORE PELLET

Preparation of Iron Ore Pellet

Iron ore fines are produced by the process of grinding the iron ore in a mortar and pestle arrangement. The prepared iron fines are screened by 72 mesh size. Minimum 400gm of -72 mesh fines were collected.

Binder: Here as a binder we use Bentonite (aluminiumphyllosilicate).

Pellet Preparation: In this experiment pellets of 15-17 mm size were prepared with help of by hand rolling of wet-72 size iron mineral fines. Pellets are prepared by the mixing of binder (2 wt. % of iron mineral). Then the pellets are placed inside the heater at 110°C for heating and discard the any water content for 120 minutes. After the completion of 2 h, the pellets were ready to be taken out.

Firing of Pellets: The iron ore pellets after taking out from the furnace were heated from ambient conditions to the desired heating temperatures (1000, 1100 and 1300°C) at the heating rate of 7°C /min. The dwell time for these heating temperatures is around 1 Hr. after

keeping the pellet for 1 hour, furnace was terminated and pellets inside the furnace were let to cool inside the furnace only. When they fully cooled, were taken outside.

3.5 Determination of Physical Properties of Fired Iron Ore pellets

The fired iron ore pellets prepared were advanced for calculating the crushing strength value.

3.5.1 Determination of Cold Crushing Strength:

Determination of compressive strength of fired iron ore pellets had been carried-out by the help of a uni -axial hydraulic press (capacity 20 tons). The indicated values of compressive strength were computed by utilizing the given below formula.

$\sigma_c = W/A$

Where,

σ_c=crushing strength in kg/cm^2.

W =maximum load for fracture in (kg).

A =area in cm^2.

3.5.2 Determination of Apparent Porosity:

The apparent porosity estimations of iron mineral pellets are determined out by utilizing kerosene as a agent as per the given below formula:

Apparent porosity = W – D/ W- (S-s)

Where,

"D"= weight of dried pellet

"W"= weight of oil saturated pellet

"S"= weight of the pellet + string while submerged in oil

's'=weight of string just while submerge in oil

3.6 REDUCTION STUDIES METHODOLOGIES:

The reduction process starts with heating the pellet in a muffle furnace from ambient temperature to the desired temperatures of reduction like 800,850, 900, 950, at a heating rate of about 10°C/minute and kept at these reduction temperatures for different length of time 15, 30, 60, 90 &120 minutes for the reduction temperatures of 800,850 and 900, and 5, 10, 15, &20 minutes for the reduction temperatures of 950. Correctly weighted of oven dried pellet (15mm approx. size) and kept in a vicinity of packing of non-coking coal ,grinded in a dimension of210 microns, in a stainless steel crucible (size: 50mm height × 25 mm dimension) which is air proof packing with an opening for flue gas. The pellets are placed in the steel crucible such that it must have to be in centre. This is done for the purpose that pellets must have totally surrounded by the reducing agents. When the pellets reached the requisite temperature, each crucible is taken out at an interval of 15, 30, 60, 90 and 120 minutes for 800,850and 950 temperature and 5, 10, 15, and 20 minutes for 950°C. After that the crucible are bring down to the ambient temperature and calculate the amount weight losses for the pellets. The extent of reduction of pellets can be determined with the help of given below formula.

%reduction = (weight loss in pellet/total oxygen content in the pellet) ×100.

3.7 DETERMINATION OF PERCENTAGE SWELLING:

Swelling can be characterised by change in the volume of the pellet in the course of reduction of iron-oxide to metallic iron. Basic reason of swelling of the pellet is Changes of crystal structure in the course of subsequent reduction of hematite to magnetite and finally wustite (FeO) to final product that is metallic iron. The above mentioned microstructural shifts are followed by increase in volume. %age swelling can be determined by:

$$\% \text{ swelling} = V_f - V_i / V_i$$

V_f= final volume of the reduced pellet

V_i= initial volume of the fired pellet.

Final and initial Volumes of the pellets can be determined by measuring radius of pellets before and after the reduction.

CHAPTER-4

RESULTS
&
DISCUSSIONS

4.1Characteristics of Selected Iron Ore and Coal:

For analysis of chemical compositions and loss on ignition values, samples were sent to Rourkela Steel Plant and results are mentioned in Table 4.1.Clearly observed from the Table 4.1, G.M.OMC Ltd iron ore sample have Fe content greater than 60%,so we can say that it's a good quality iron ore. Impurity concentration is very small and it's very good for us. Because alumina and silica has deleterious effect in extraction of iron form iron ore. Alumina forms a viscous slag during smelting, requires high coke rate and results in some troubles during tapping of viscous slag. Silica forms grey iron. Grey iron is brittle but easier to get a good finish Proximate analysis of the sample gives the result: fixed carbon content=40.32, ash concentration=32.56 volatile materials= is 27.26. The data for sulphur is taken from the work of M.kumar and patel [2].

4.2 Effects of Binder Content on the Crushing Strength and Porosity of the Pellets:

As we increases the content of binder, crushing strength of the pellet increases. Lowest crushing is indicated at 2wt% binder content and as the binder content increases to 6wt%, crushing strength increased. Porosity is independent of binder content and remains almost constant with increase in binder.

4.3 Effect of Reduction Temperature on the Degree of Reduction and Extent of Swelling of Fired Iron Ore Pellets:

Reducibility of iron ore pellet increases with the increase in reduction temperature. One may say that increase in the reduction of the iron ore pellet with increase reduction temperature be due to greater release of gaseous reducing elements (carbon monoxide and hydrogen gas)

coming out from the devolatilization of coal and reaction of solid carbon with oxygen to form carbon monoxide. Another reason of increase in degree of reduction of iron ore pellet is diffusion of reducing gases through layer of pellet.

The degree of swelling initially increases a slightly with the increase in the reduction temperature and after that it shows decreasing trend as we increase the reduction temperature. Earlier increase can be attributed to higher degree of reduction and growth of fibrous phase. And the decline in swelling after initial hike is due to sintering of fibrous material at higher temperature.

4.4 Effect of Reduction Time on Degree of Reduction and Extent of Swelling of Fired Iron Ore Pellets:

The extent of reduction of pellet increases as we increase the time at a given reduction temperature. The increasing trend in reduction is actually to the participation of pellets with the reducing elements like solid carbon, hydrogen gas and carbon monoxide for a longer length of time .The greater degree of reduction in initial phase might be given to the mixed effect of lesser resistance provided to the passage of reducing elements inside the pellet and major role played by released volatile matter initially.

The degree of swelling shows increasing trend with the rise in reduction time at a given temperature of reduction and firing temperature. This kind of phenomenon is happened due to development of iron fibers inside the pellet matrix without any constraint to grow.

4.5 XRD Analysis of Reduced Iron Ore Pellets:

The XRD patterns of G.M.OMC Ltd iron ore pellets reduced at temperatures of 800, 850, 900 and 950°C for a time period of 60, 30, 90 minutes respectively by Basundhara non-coking coal, which is shown in respective figures. It is quite clear from the figures that the pellet which is reduced at lower temperatures has majority of FeO peaks of higher intensities. But as

we are going for higher reduction temperatures FeO phases are keep on decreasing and at 950°C almost only Fe phase is present. This result is also supported by EDX analysis in which we can see that as we increase the reduction temperature, Wt.% of oxygen is continuously decreasing from 800°C to 950°C.

4.6 Scanning Electron Micrographic Study of the Reduced Pellets:

As showed by fig 4.11- 4.12fractured surfaces are grown in the iron ore matrix due to swelling, the cracks formed in the reduced pellets are more noticeable at 850°C as compared to Cracks at 800°C, 900°C and 950°C because of sintering of the iron fibers reduced at high temperatures as a result packing of iron ore matrix had occurred.

Sintering of the pellet matrix is of greater extent in case of pellet reduced at 950°C as compared to the pellets reduced at lower temperatures i.e., 850°C.

The excessive swelling of the iron ore pellets at lower temperatures is due to fibrous growth of iron whiskers and formation of more cracks in the pellet matrix, which is also visible in the SEM photographs.

TABLE 4.2Chemical Composition and Loss on Ignition of Iron ore

Iron Ore Source	Chemical Composition (weight percent on dry basis)						
	Fe (Total)	Fe_2O_3	Al_2O_3	SiO_2	TiO_2	MnO	LIO*
G.M.OMC Ltd.	63.46	90.80	2.73	3.20	0.10	0.01	3.16

TABLE 4.3 Proximate Analysis of Non-coking Coal

Non-coking Coal	Volatile Matter (%)	Ash (%)	Fixed Carbon (%)	Sulphur content (%)
Basundhara non-coking coal	27.2	32.56	40.32	0.45

TABLE 4.4Analysis of Physical Properties of Fired G.M.OMC Ltd Iron Ore Pellets

Binder	Binder (%)	Firing Conditions		Drop No		Crushing strength Kg/ Pellet	Porosity (%)
		Firing Temp(°C)	Firing Time(hr.)	Oven dried	Fired		
Bentonite	2	1100	01	01	09	52	22.5
	4	1100	01	02	439	202	22.45
	6	1100	01	04	611	237	21.6

TABLE 4.4 Values of Degree of Reduction and Swelling Fired G.M.OMC Ltd Haematite Iron ore pellets Reduced in Basundhara non-coking coal

Binder	Binder (%)	Pellet composition: –72#					
		Firing Conditions		Reduction Conditions		Degree of Reduction (%)	Swelling (%)
		Firing Temp(°C)	Firing Time(hr.)	Reduction Temp(°C)	Reduction Time(Min)		
Bentonite	2	1100	1	800	15	44.64	21
					30	41.13	27
					60	46.533	23.5
					90	33.56	19.22
					120	47.86	26
				850	15	64.74	42.33
					30	56.56	33.77
					60	70.80	54.42
					90	53.84	14.45
					120	92.59	47.033
				900	15	60.86	31.35
					30	64.59	32.75
					60	96.77	44.38
					90	94.677	16.48
					120	96.06	10.464
				950	5	80.88	22.99
					10	84.88	23.61
					15	96.02	3.926
					20	90.93	31.055

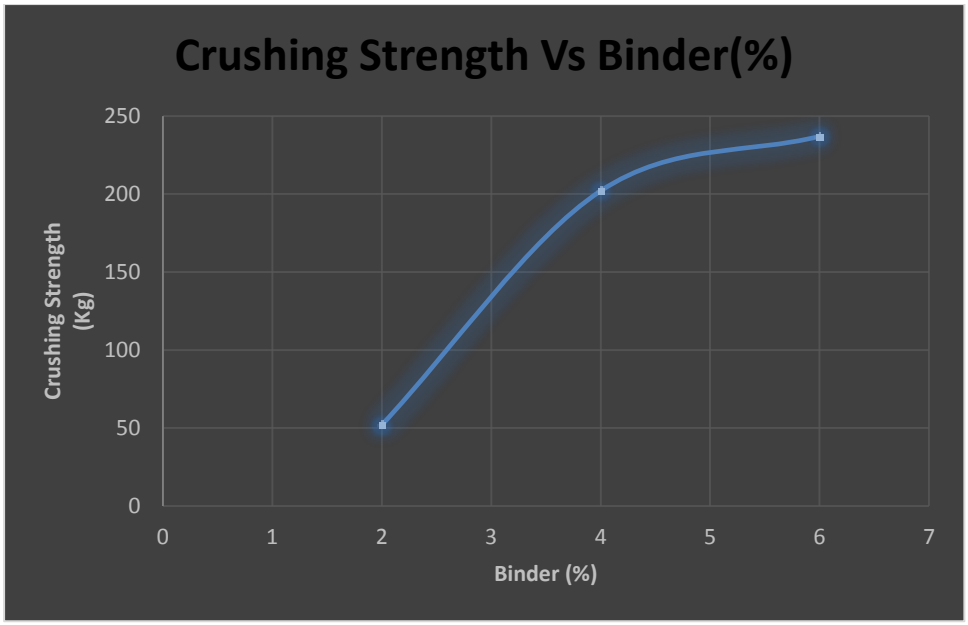


Figure 4.1: **Effect of binder content on the Crushing Strength of fired G.M.OMC Ltd. Iron ore pellets [2% binder,-72#].**

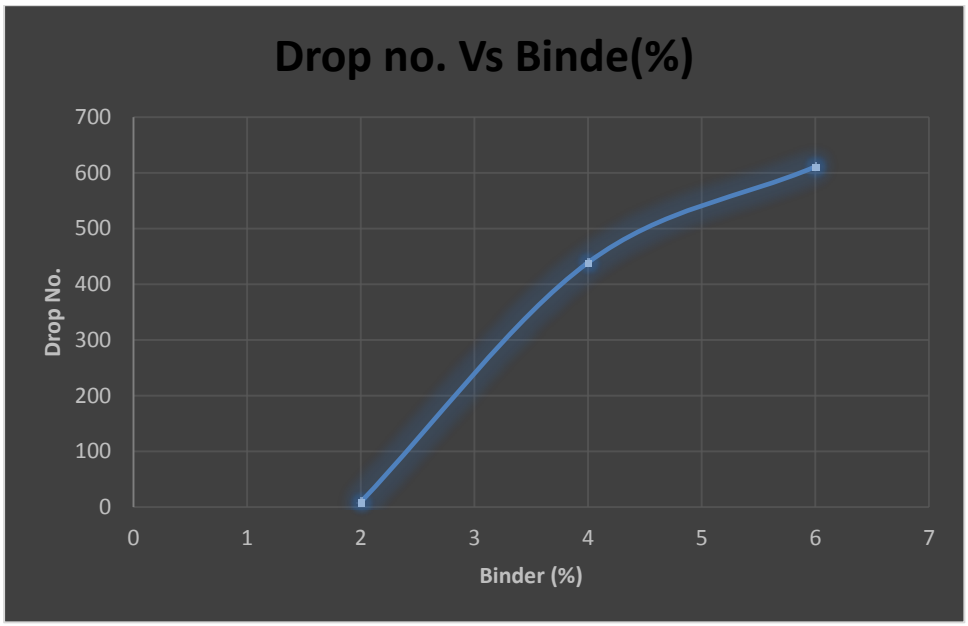


Figure 4.2: Effect of binder content on the Drop No. of fired G.M.OMCLtd iron ore pellets [2% binder,-72#].

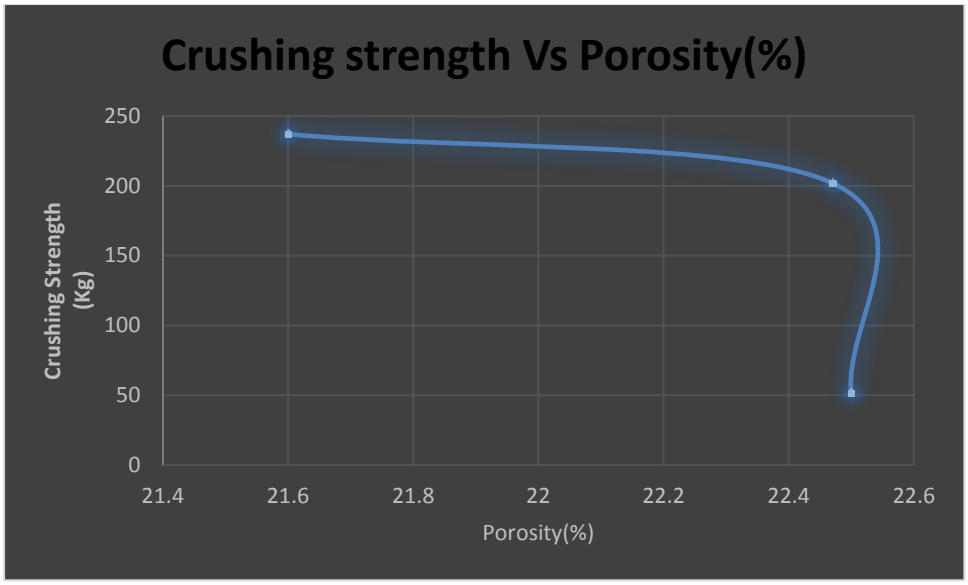


Figure 4.3: Effect of Porosity (%) on the Crushing Strength of fired G.M.OMC Ltdiron ore pellets [2% binder,-72#].

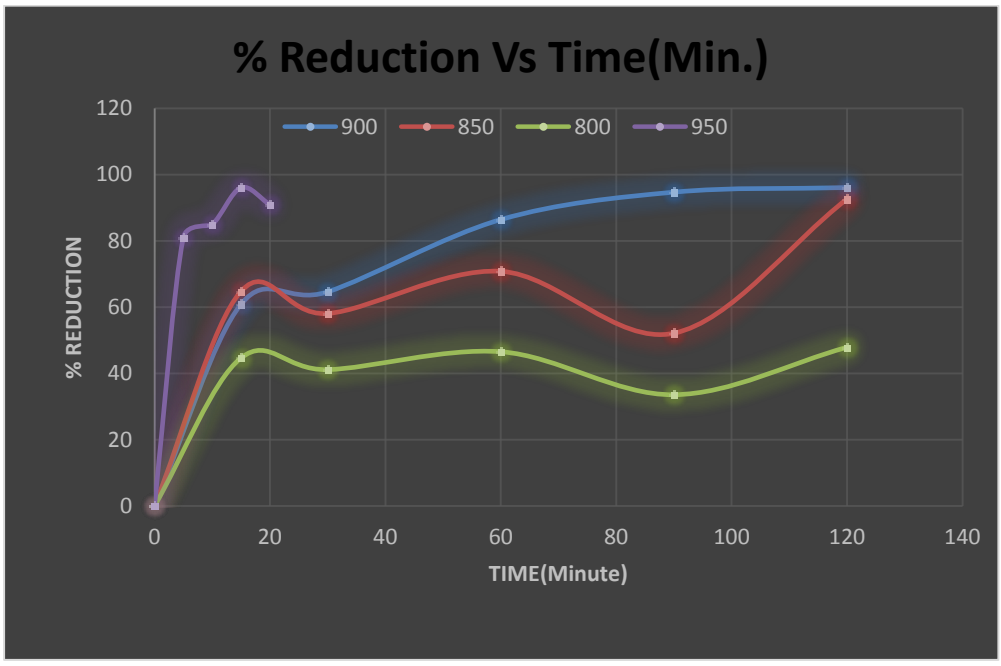


Figure 4.4: Effects of Time on Degree of Reduction of G.M.OMC Ltdiron ore pellets [2% binder, firing temperature 1100°C,-72#].

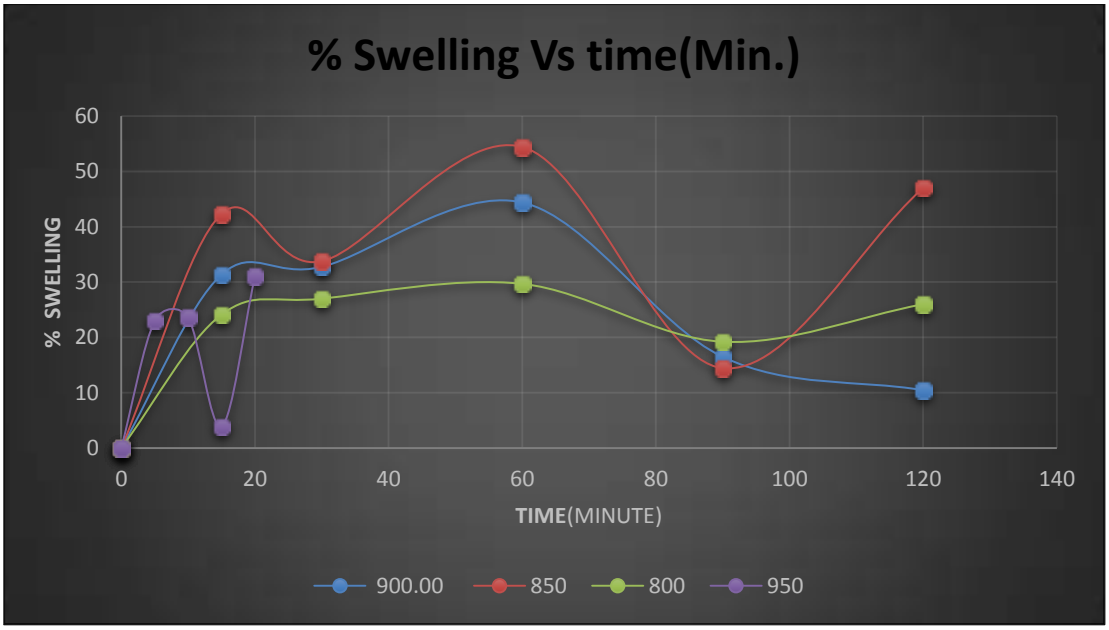
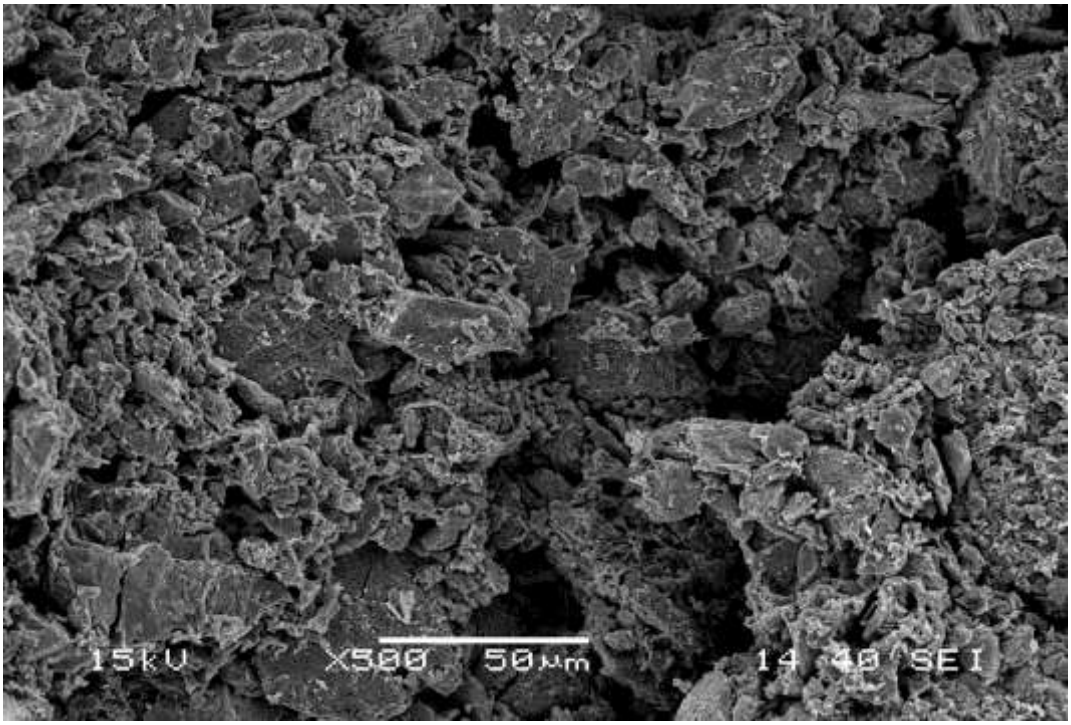


Figure 4.5: Effects of Reduction Time (min) on Swelling (%) of G.M.OMC Ltd iron ore pellets [2% binder, firing temperature-1100°C,-72#]



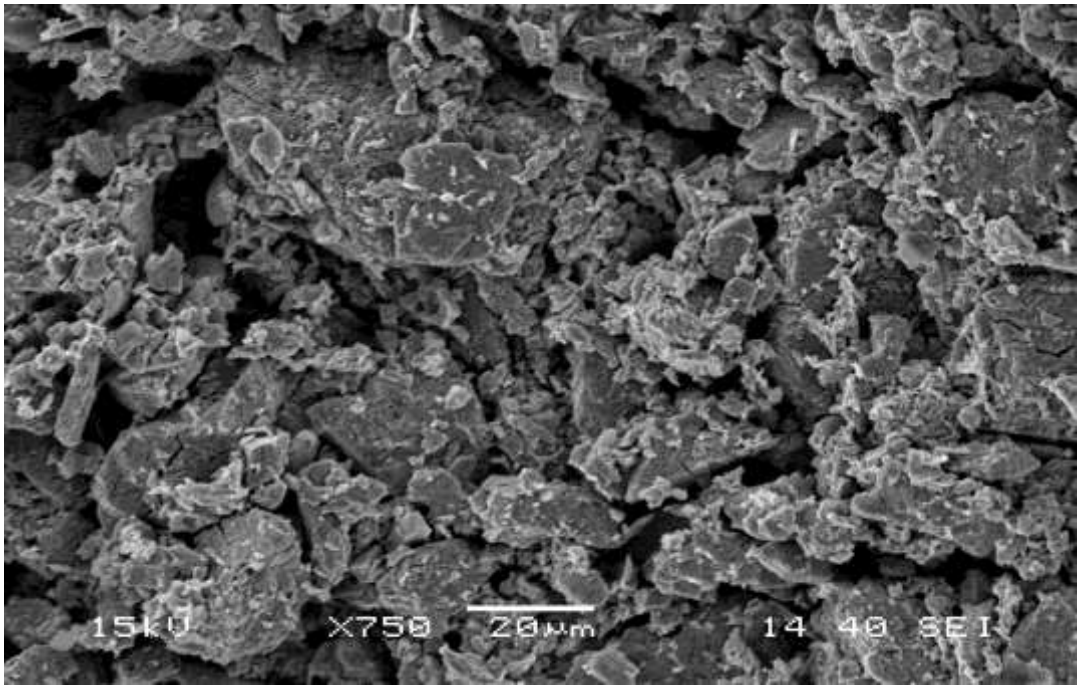
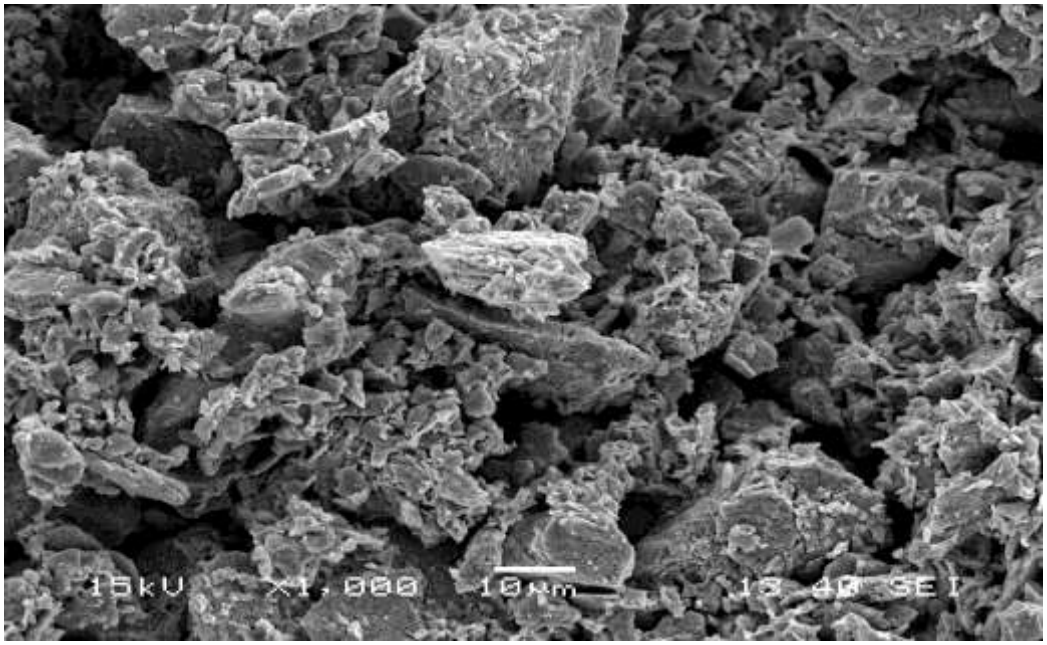


Fig 4.6: SEM photograph of reduced G.M.OMC Ltd iron ore pellet fired at 1100°C for 1 hour [reduction temperature-800°C, 2% binder, reduction time-90 min,-72#]



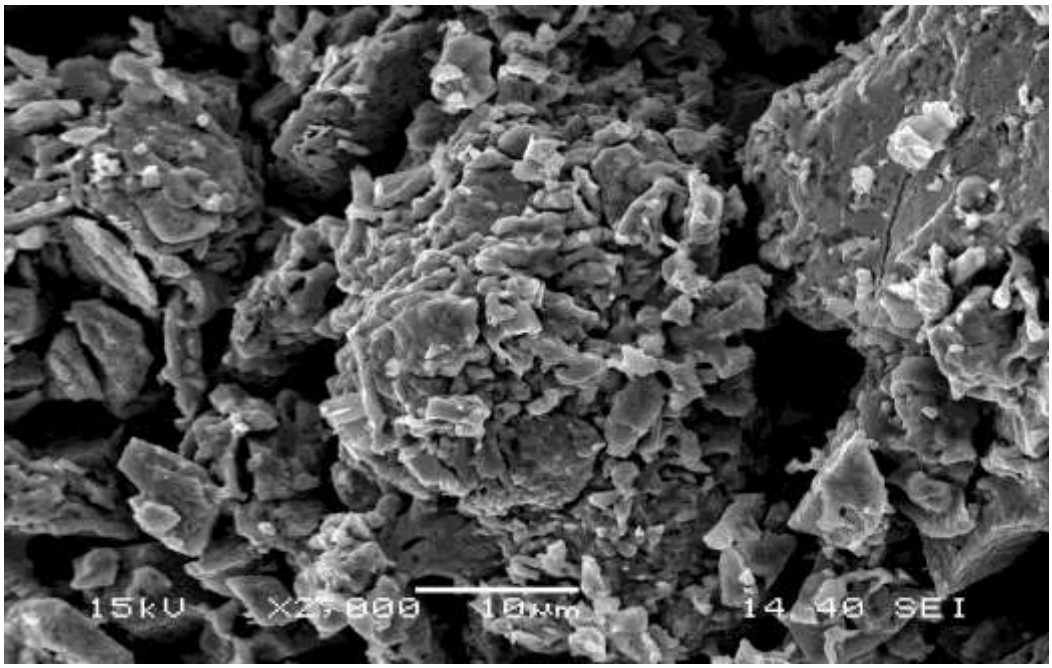


Fig 4.7: SEM photograph of reduced G.M.OMC Ltd iron ore pellet fired at 1100°C for 1 hour [reduction temperature-800°C, 2% binder, reduction time-90 min,-72#].

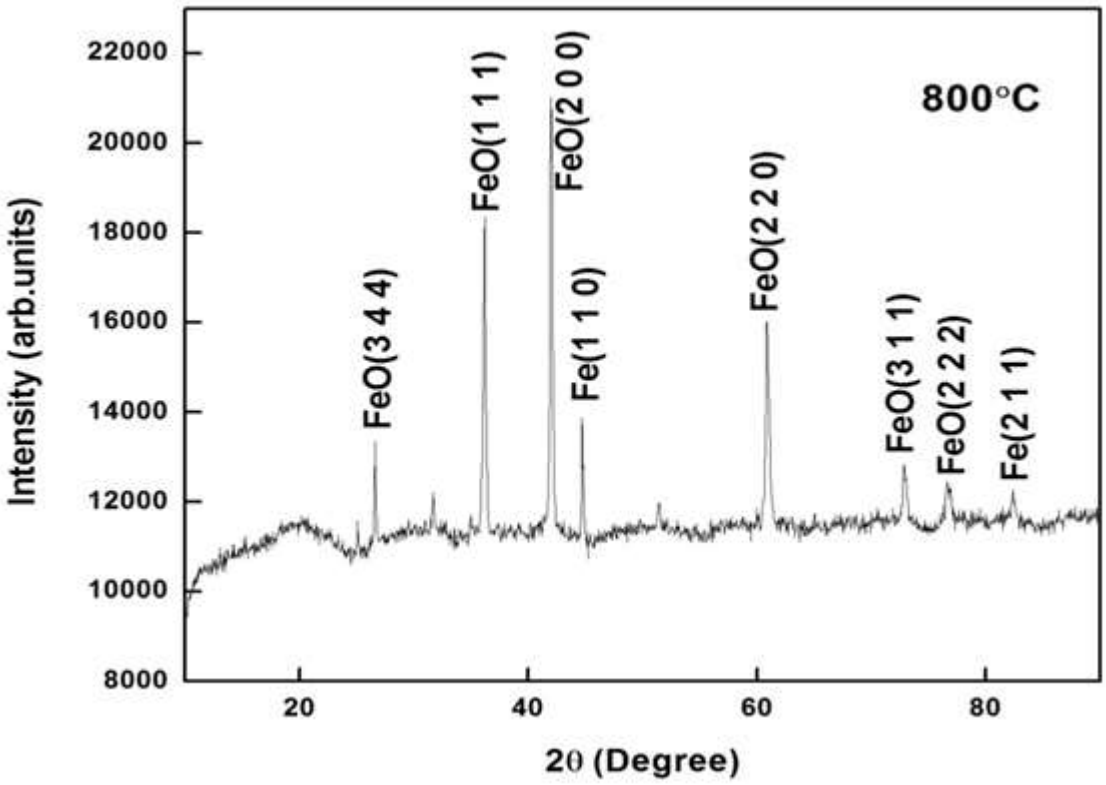


Fig 4.8: XRD Patterns of G.M.OMC Ltd iron ore pellets reduced at800°C,time:60 min

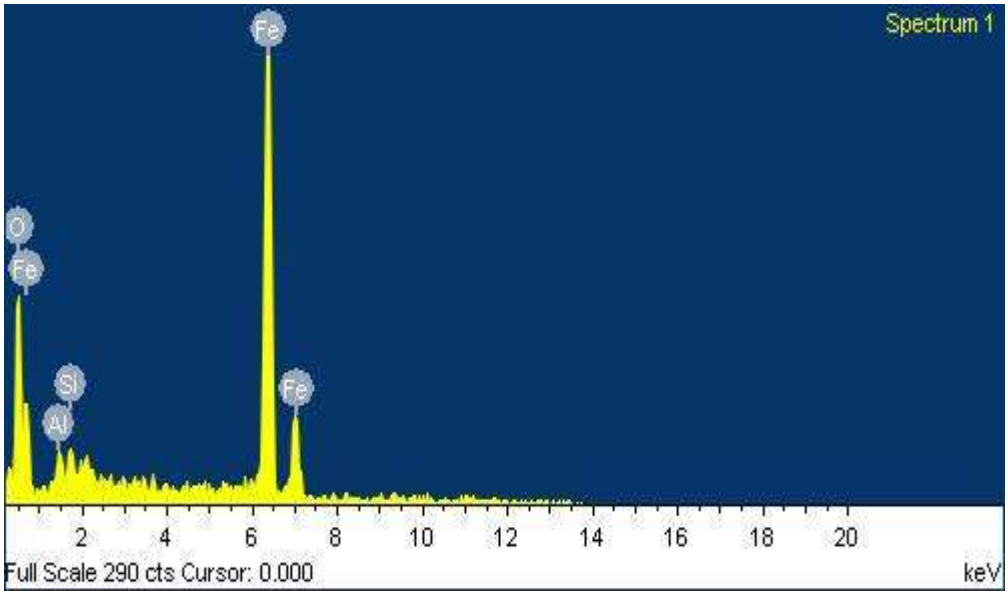


Fig 4.9: EDX images of iron ore pellet reduced at 800°C.

Element	Weight%	Atomic%
O	10.47	28.23
Al	1.47	2.35
Si	1.28	1.98
Fe	86.84	67.43
Total	100.00	

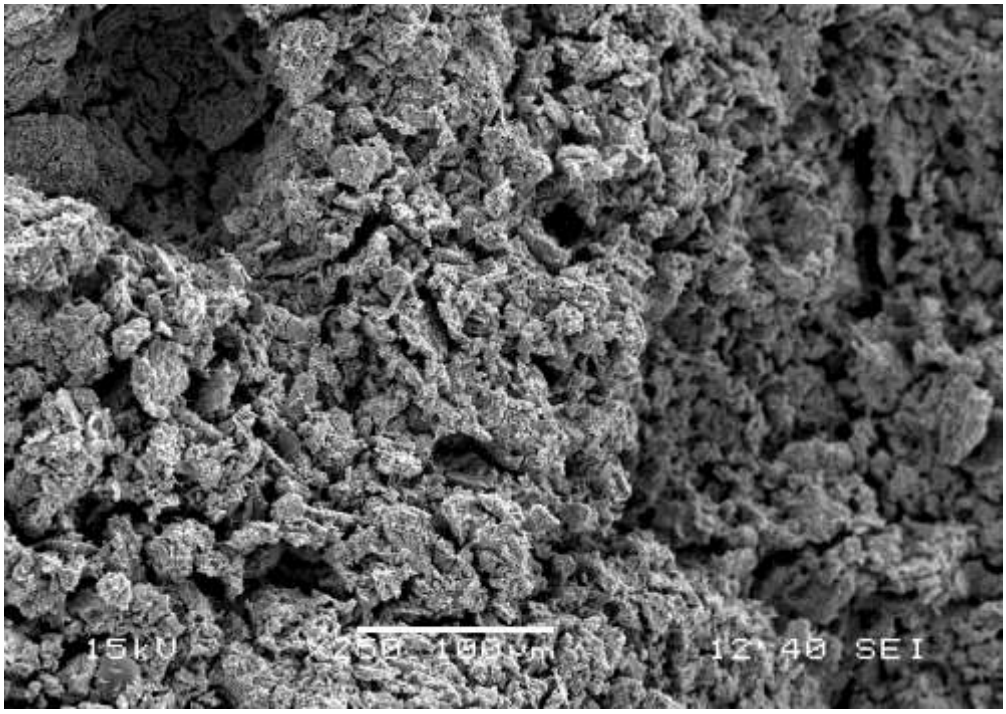
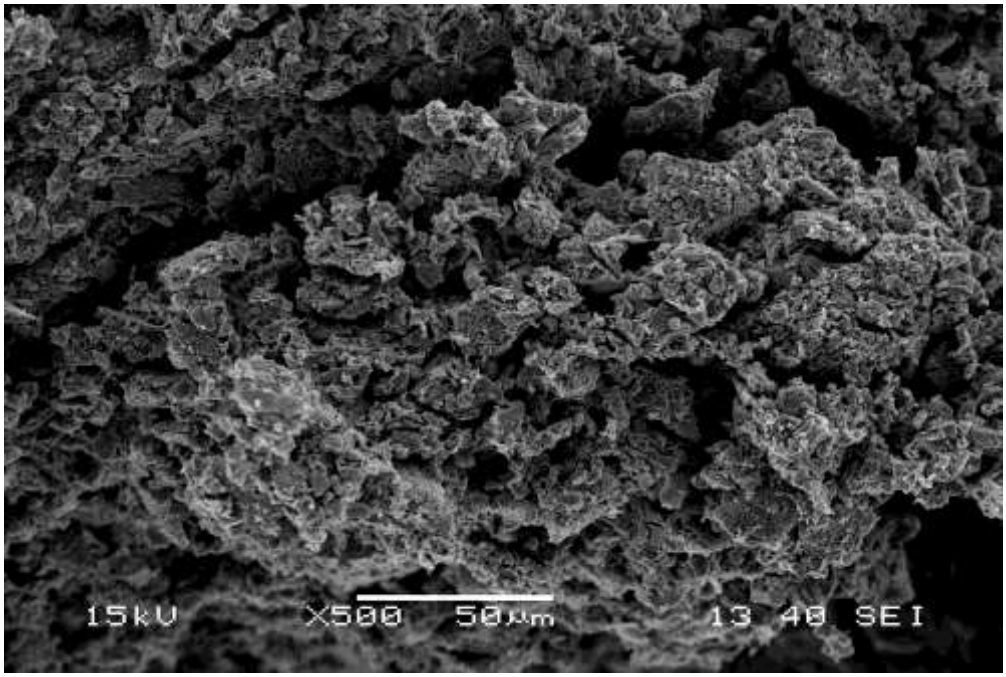


Fig 4.10: SEM photograph of reduced G.M.OMC Ltd. iron ore pellet fired at 1100°C for 1 hour[reduction temperature-850°C, 2% binder, reduction time-60 min,-72#].



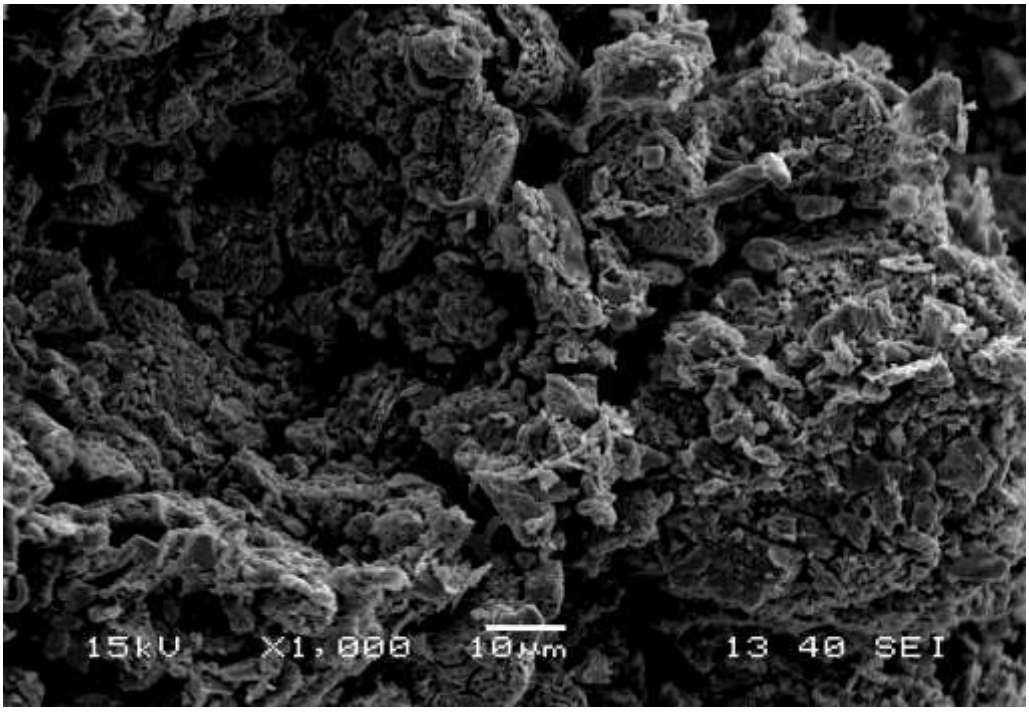


Fig 4.11: SEM photograph of reduced G.M.OMC Ltd. iron ore pellet fired at 1100°C for 1 hour [reduction temperature-850°C, 2% binder, reduction time-60 min,-72#].

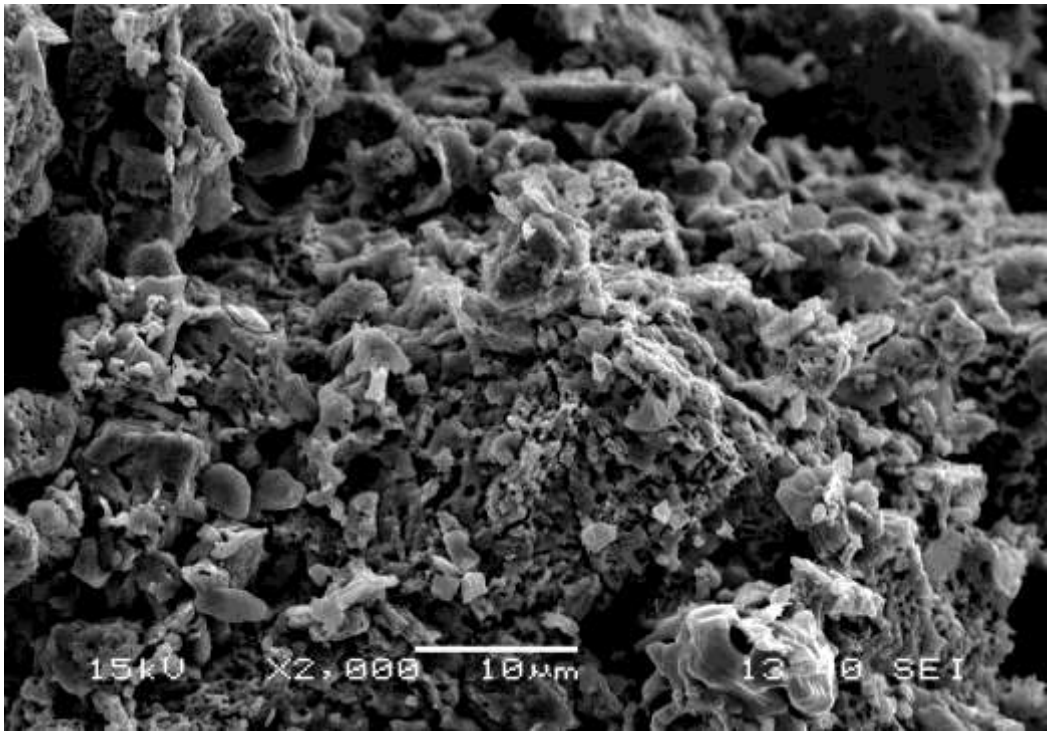


Fig 4.12 SEM photograph of reduced G.M.OMC Ltd. iron ore pellet fired at 1100°C for 1 hour [reduction temperature-850°C, 2% binder, reduction time-60 min,-72#]

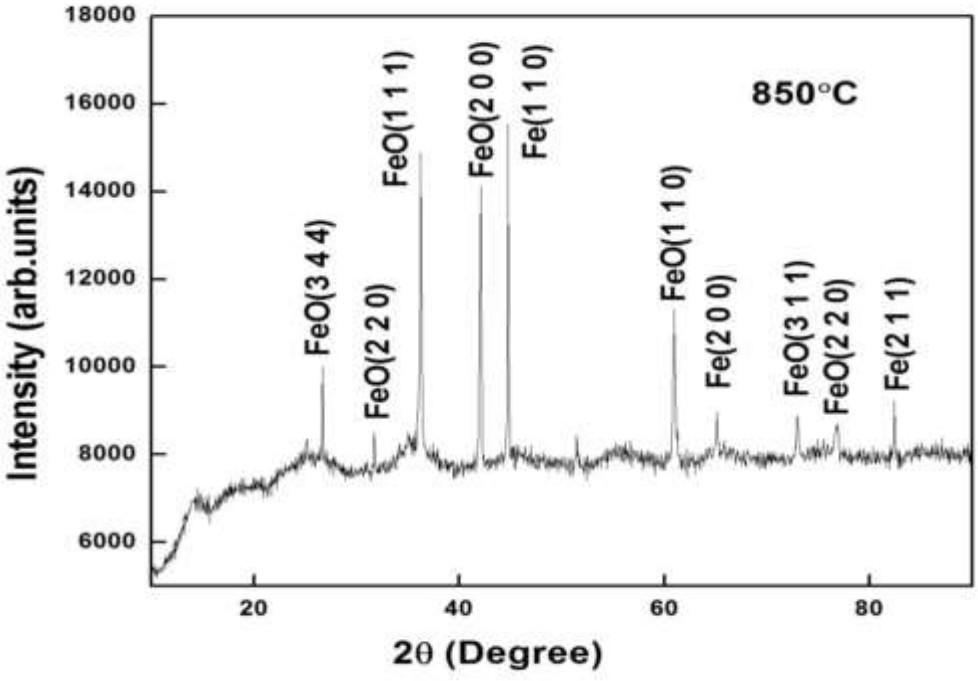


Fig-4.13 XRD Patterns of G.M.OMC Ltd iron ore pellets reduced at 850°C, Time:30min

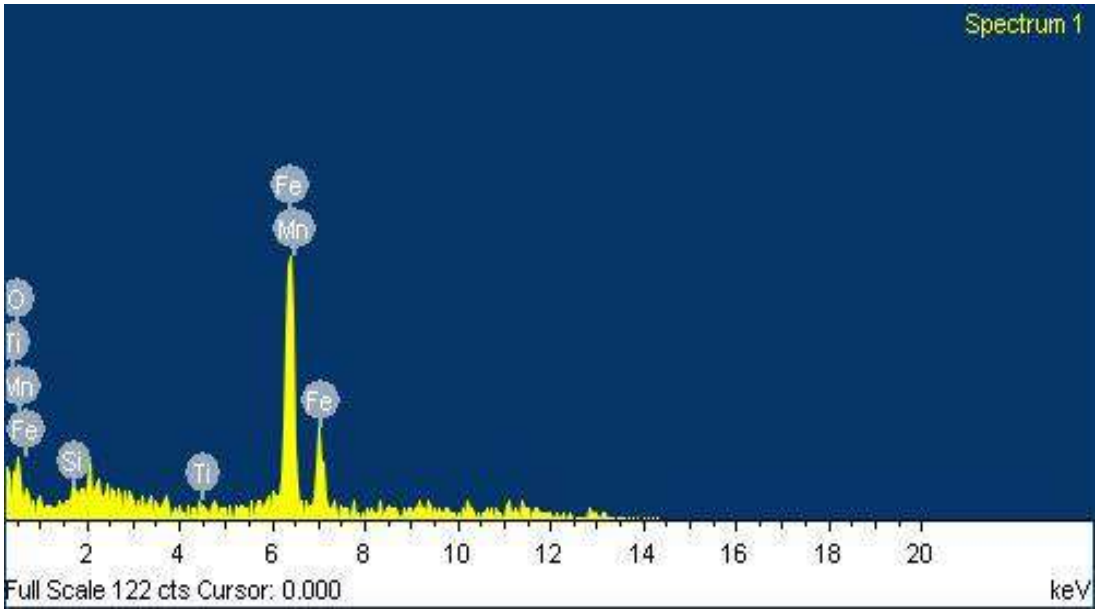
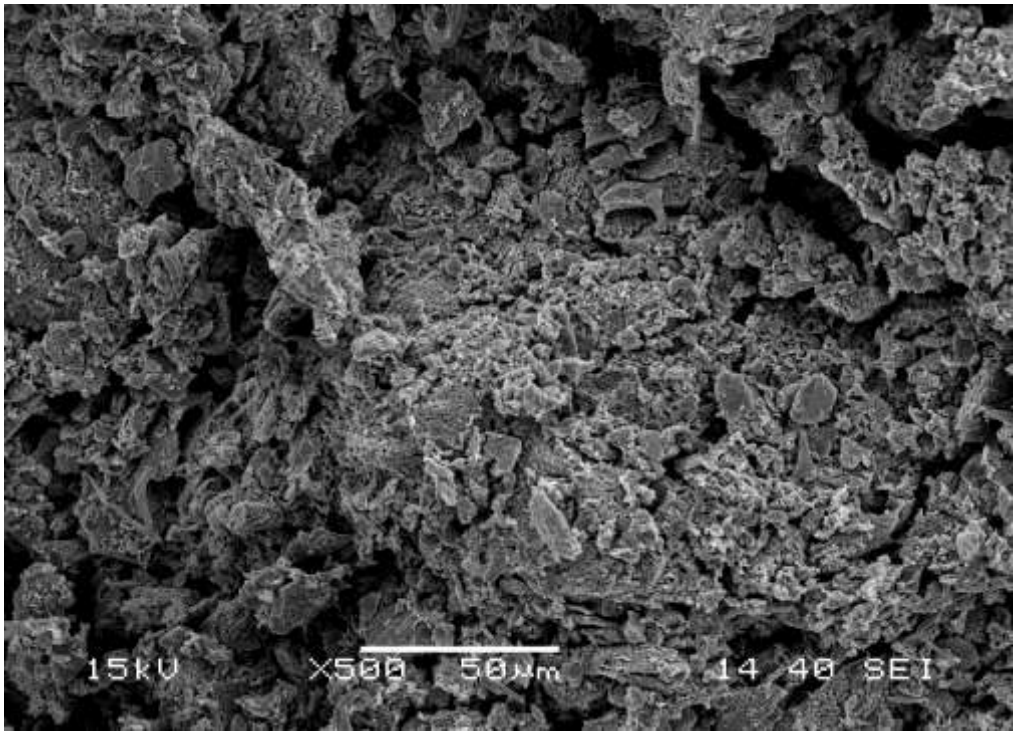


Fig 4.14EDX images of iron ore pellet reduced at 850°C.

Element	Weight%	Atomic%
O	3.65	11.59
Si	**0.60**	**1.08**
Ti	1.11	1.18
Mn	0.09	0.08
Fe	94.56	86.07
Total	100.00	



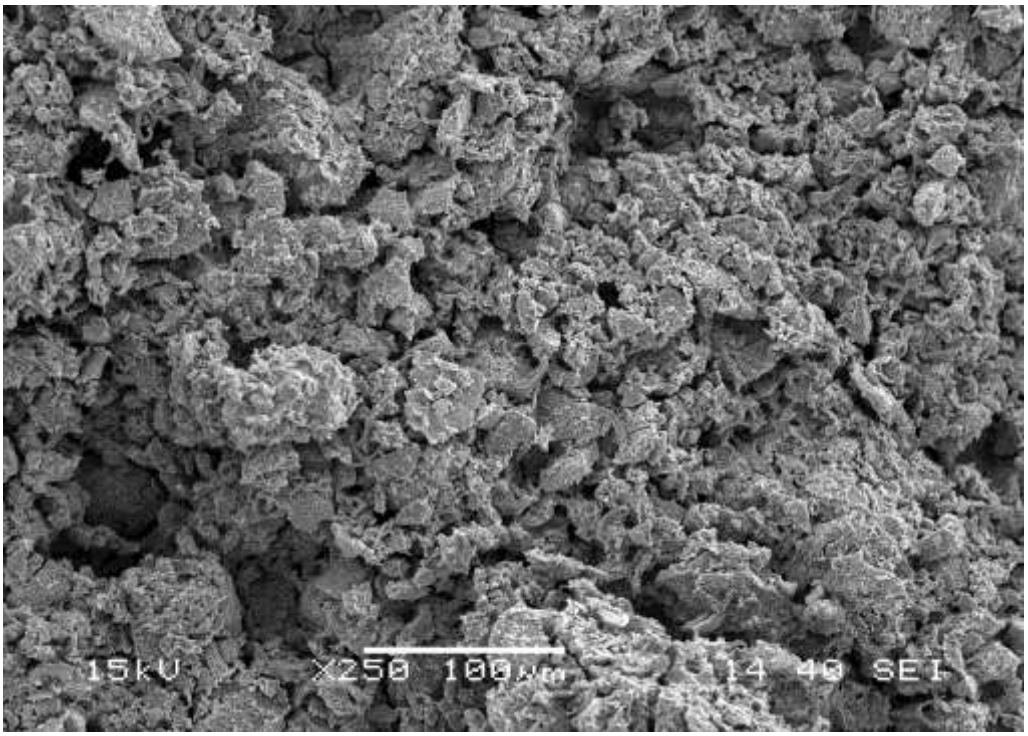
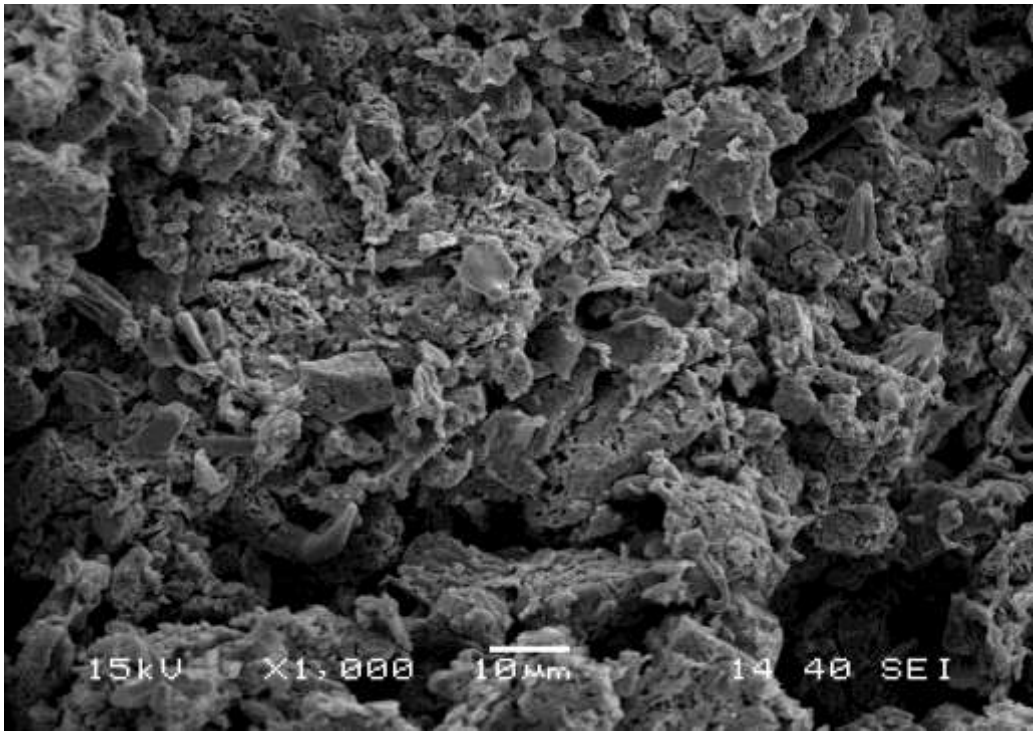


Fig 4.15:SEM photograph of reduced G.M.OMC Ltd iron ore pellet fired at 1100°C for 1 hour [reduction temperature-900°C, 2% binder, reduction time-30 min,-72#]



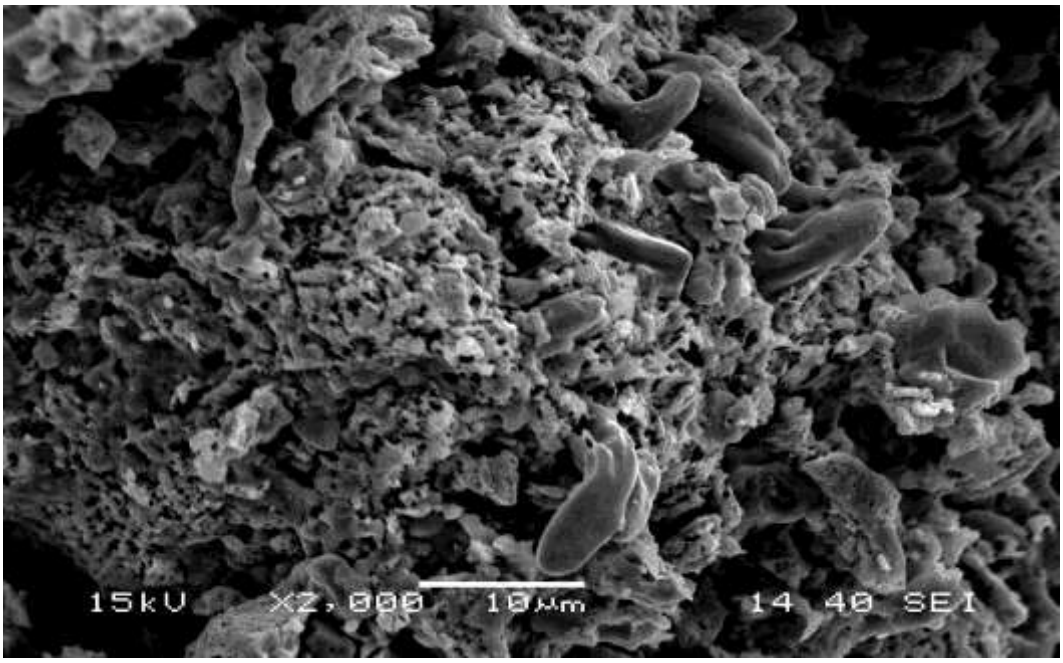


Fig 4.16:SEM photograph of reduced G.M.OMC Ltd iron ore pellet fired at 1100°C for 1 hour [reduction temperature-900°C, 2% binder, reduction time-30 min,-72#]

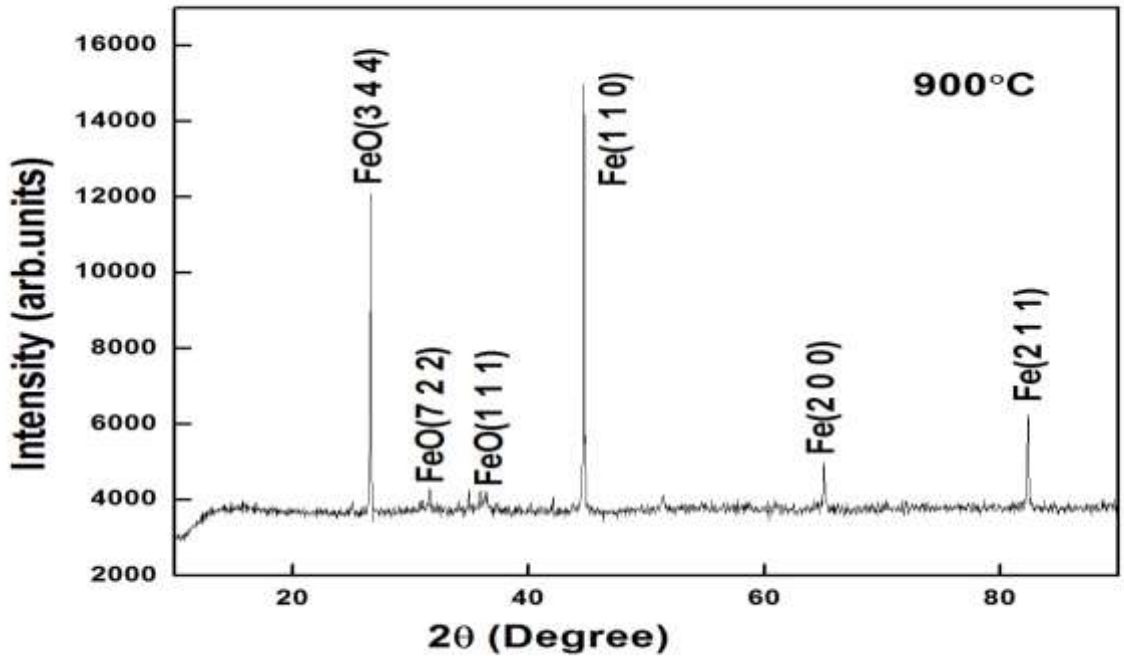


Fig 4.17: XRD Patterns of G.M.OMC Ltd iron ore pellets reduced at 900°C, Time: 90 min

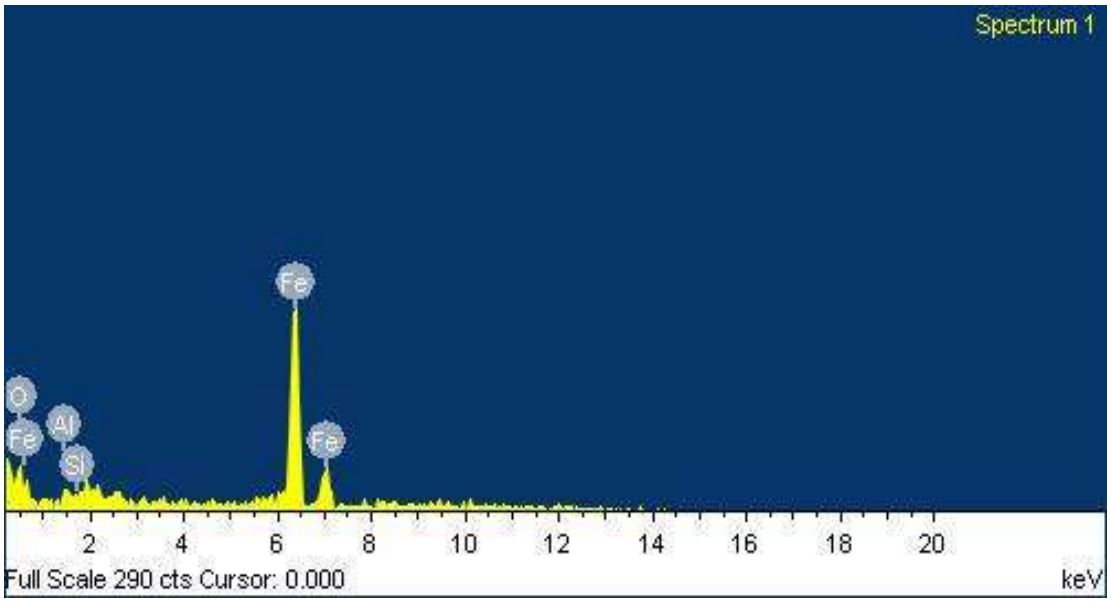


Fig 4.18:EDX images of iron ore pellet reduced at 900°C.

Element	Weight%	Atomic%
O	1.30	4.32
Ai	1.44	2.84
Si	0.00	0.00
Fe	97.27	92.84
Total	100.00	

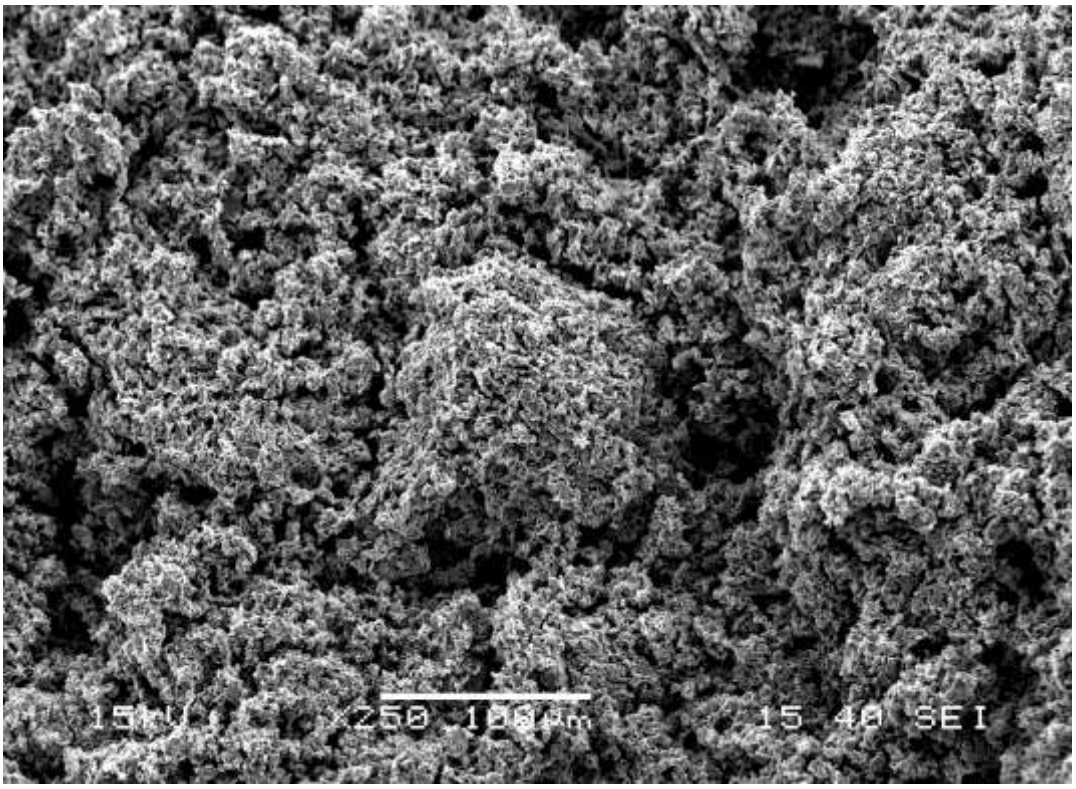
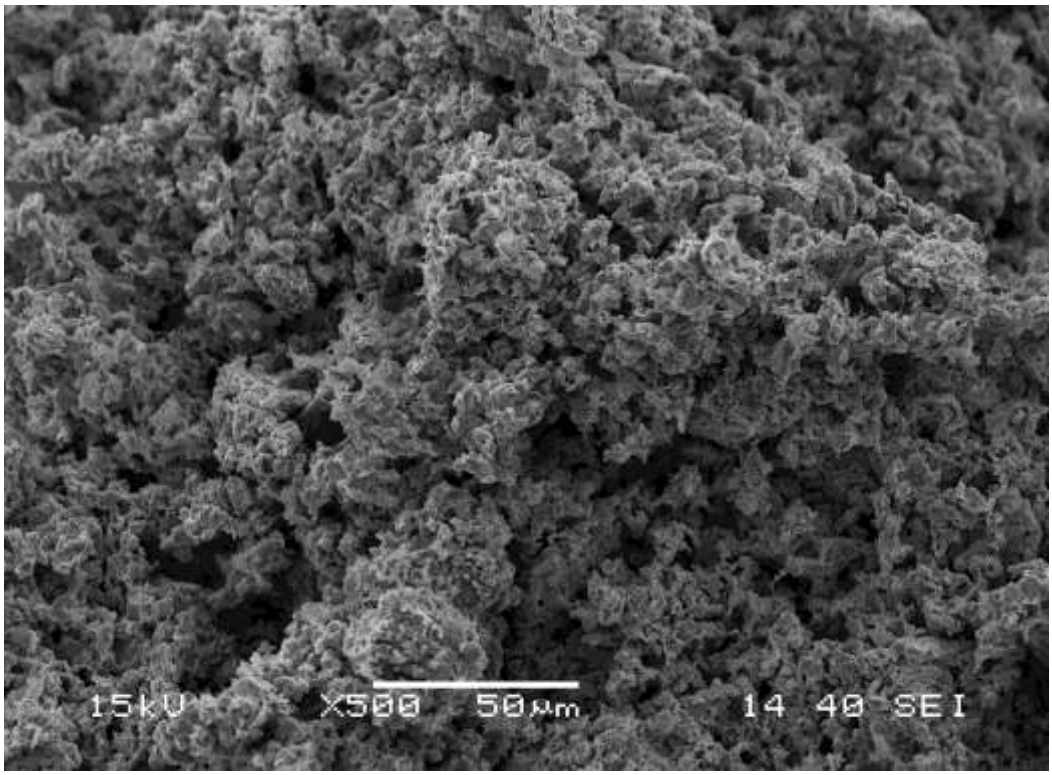


Fig 4.19:SEM photograph of reduced G.M.OMC Ltd iron ore pellet fired at 1100°C for 1 hour [reduction temperature-950°C, 2% binder, reduction time-20 min,-72#]



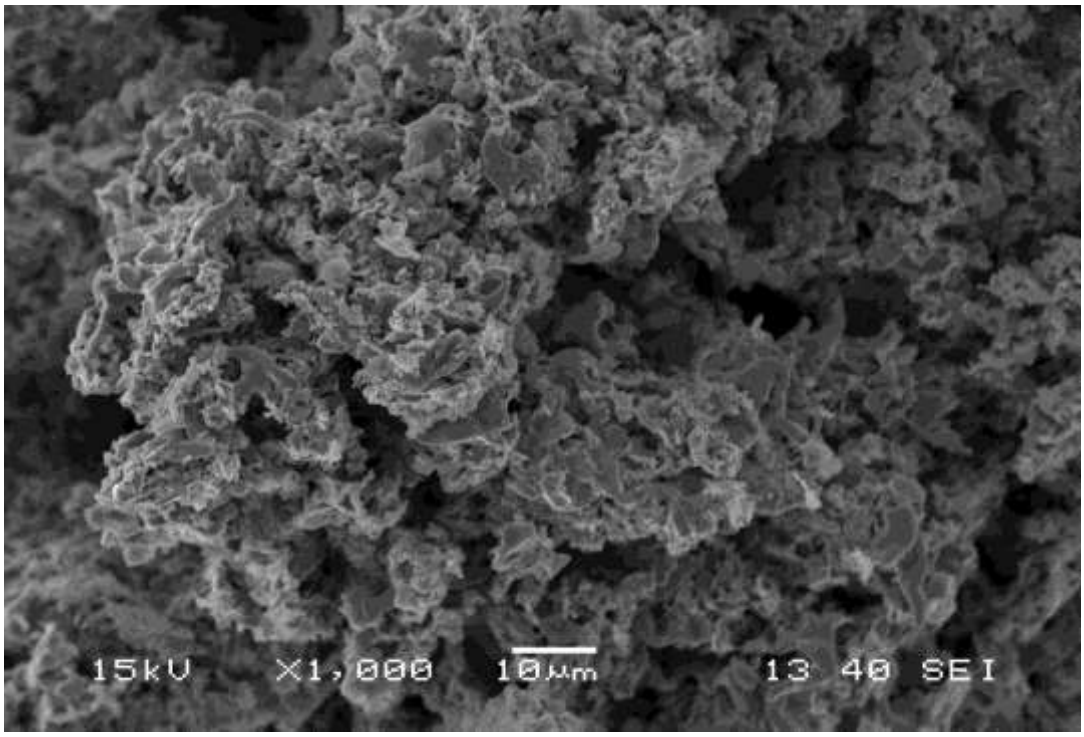


Fig 4.20: SEM photograph of reduced G.M.OMC Ltd iron ore pellet fired at 1100°C for 1 hour [reduction temperature-950°C, 2% binder, reduction time-20 min,-72#]

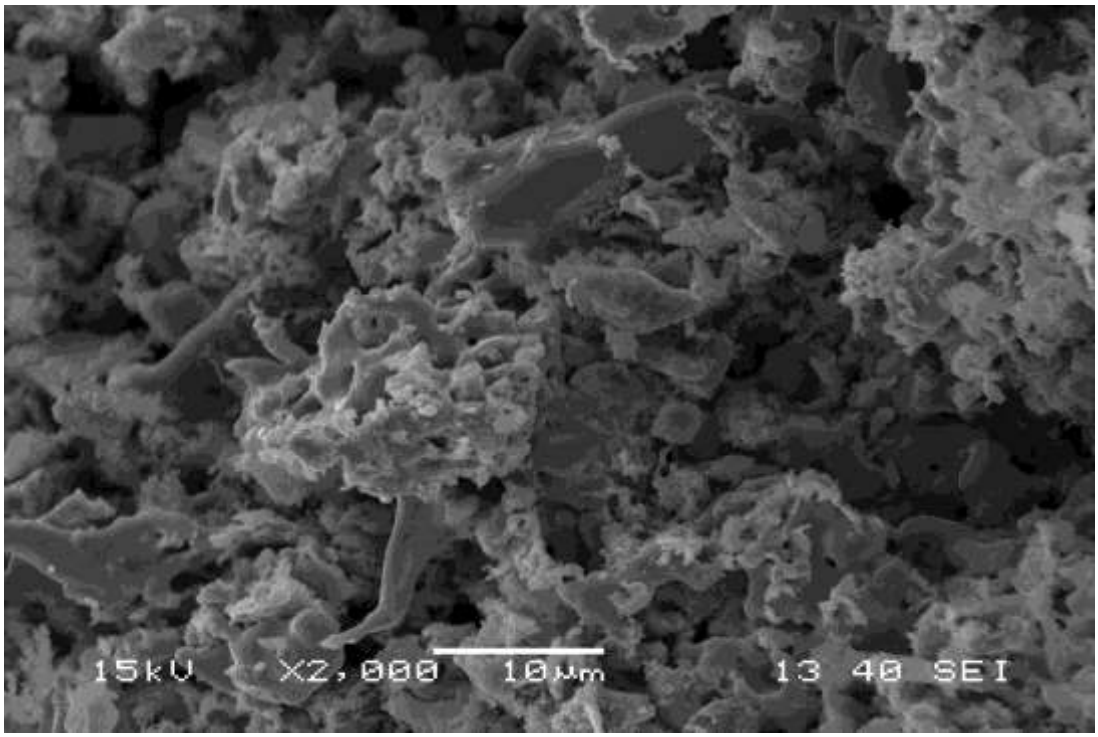


Fig 4.21 SEM photograph of reduced G.M.OMC Ltd iron ore pellet fired at 1100°C for 1 hour [reduction temperature-950°C, 2% binder, reduction time-20 min,-72#]

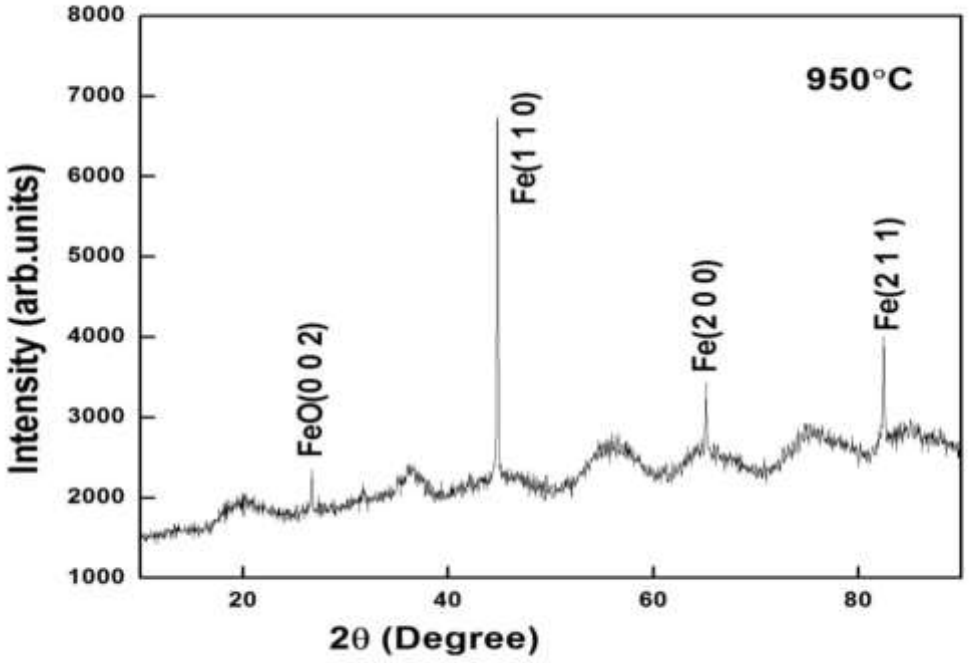


Fig 4.22: XRD Patterns of G.M.OMC Ltd iron ore pellets reduced at 950°C, Time: 15min

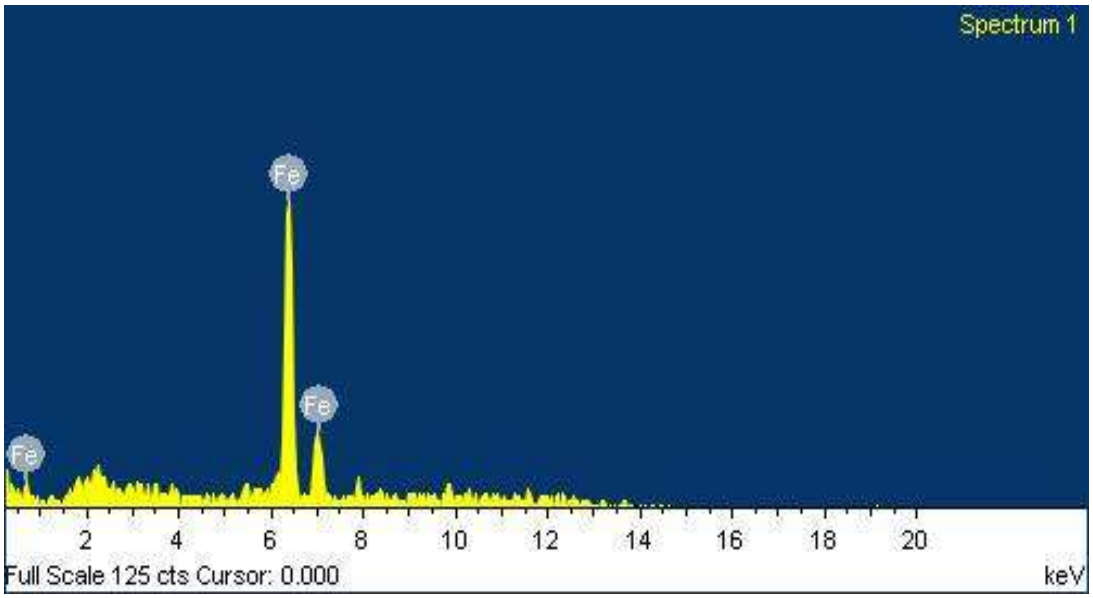


Fig 4.23: EDX images of iron ore pellet reduced at 950°C.

Element	Weight%	Atomic%
Fe	100.00	100.00
Total	100.00	

CHAPTER-5

CONCLUSION

CONCLUSIONS:

From the results of the present project work, the following conclusions may be drawn.

- Physical properties are directly linked with binder content. As we increase the binder content, crushing strength of the pellet increases. Max. Crushing strength is found at 6% (Wt. %) and min.at 2 %(Wt. %).Drop number also increases with increase in binder content.

- As we increase the reduction temperature, degree of reduction of the pellet increases. This is because of the diffusion of more and more reducing gas through the pellet.

- The degree of swelling first increases and then decreases with increase in reduction temperature, maximum swelling is found at temperature 850°C Whereas shrinkage was found in temperature 900°C & 950°C.

- As we left the pellet for longer period of time at a particular reduction temperature, higher degree of reduction is observed.

- It is confirmed from the XRD analysis of the pellet that as we increase the reduction temperature, amount of FeO phase decreased.

- SEM pictures confirm that greater densification occurs at 900°C and 950°C respectively due to sintering of the pellet matrix respectively as compared to 850°C.

CHAPTER-6

FUTURE WORK

FUTURE SCOPE OF THE PROJECT:

The works carried out in this area may be extended in the future by other investigators. The suggested future work is as follows-

1. Detailed studies on reduction and swelling behaviour of fired iron ore pellets may be carried out with other non-coking coals and iron ores of Orissa, Jharkhand, and Chhattisgarh and nearby areas.

2. This work may be extended for study on reduction and swelling behaviour of iron-ore lumps.

3. Similar studies may be carried out with other binders and iron ore fines.

CHAPTER-7

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